Fonio,
an African cereal

Jean-François Cruz, Famoï Béavogui

with the collaboration of
Djibril Dramé and Thierno Alimou Diallo

cirad

I.R.A.G.

Fonio, an African cereal

Jean-François Cruz and Famoï Béavogui
with the collaboration of
Djibril Dramé and Thierno Alimou Diallo

This book is the updated translation of an original book titled "*Le fonio, une céréale africaine*" (by Jean-François Cruz, Famoï Béavogui, with the collaboration of Djibril Dramé) and published in 2011 by Éditions Quæ, CTA, Presses agronomiques de Gembloux, collection Agricultures tropicales en poche.

ISBN Quæ : 978-2-7592-1039-8

Publication of this English version is possible thanks to the Aval Fonio project (2012-2016) financed by the African Union (EuropAid procedure). The views expressed herein are those of the authors and do not necessarily represent those of the African Union or the European Commission. The African Union and the European Commission are not responsible for any use that may be made of the information contained therein.

ISBN: 978-2-87614-720-1
CIRAD 2016
http://www.cirad.fr/en/

Table of contents

Acknowledgements

The authors would like to thank everyone who has collaborated, directly or indirectly, in the three main "Fonio" projects executed since the early 2000s, and in some way made the completion of this work possible, and in particular:

In France, Francis Troude and François Mazaud, now retired, who from their position in the FAO, respectively promoted and supervised the first fonio post-harvest technology improvement project.

Nicolas Bricas, who was the initiator of the research undertaken by CIRAD on this cereal. The researchers and technicians at CIRAD Montpellier, who have participated in the various fonio projects: Ms Geneviève Fliedel, Ms Sandrine Dury, Ms Mila Lebrun, Thierry Goli, Thierry Ferré, Michel Rivier, Jean-Michel Méot, Patrice Thaunay, Joël Grabulos, Julien Ricci, Ms Virginie Lemaitre, Antoine Delpech, Jean-Paul Fleuriot, Olivier Gibert, Jacques Chantereau, Francis Forest, Didier Richard, Patrick Dugué, Frederic Lançon, Bernard Bridier, Jean-Luc Ndiaye, Sloan Saletes and for administrative support and promotion, Benoit Cervello, Ms Pascale Lantier, Ms Cindy Van Hyfte, Ms Nadine Lopez and Ms Anne Laure Perignon.

Private sector partners: Philippe Gauthier from Racines, Christophe Eberhart and Ms Pauline Huet from Éthiquable, Ms Rachel Revesz from Gaïa, and Jacques Alvernhe from the NGO Le Damier.

In Guinea, the researchers and technicians from IRAG (Guinea Agronomic Research Institute): Thierno Alimou Diallo, Sawa Camara, Youness Chaloub, Mamadou Minthé Camara, Ansoumane Sané, Moussa Doumbouya, Martin Tioutioure Camara, Saïdou Diallo, Souleymane Sakho from the Bareng/Timbi Madina IRAG Centre and Ms Madina Ndiaye from the IRAG Foulaya/Kindia Centre in Middle Guinea. Jacques Gigou (CIRAD/IRAG), N'Famara Cissé, Gansilé Nieba, Ms M'Mah Aïcha Kollet Soumah, N'konou Doumbouya from the Bordo/Kankan IRAG centre in Upper Guinea.

Private sector partners: Ms Habiba Diallo, Ms Hadja Aminata Diop, Ms Barry and the many other fonio processors based in Kindia. Adboulaye Diallo, processor based in Labé, Francis Loua, self-employed mechanic based in Labé; El Hadj Tamsis Sow from the village of Seghen, and El Hadj Madamou Seydou Gallé Diallo from the Fouta-Djalon Farmers' Federation.

Ms. Zenab Diallo, Governor of the Common Fund for Commodities (CFC) in Guinea.

In Mali, Djibril Dramé and the technology, agronomy and socio-economics teams from the Mali Institute for Rural Economy (IER), and in particular

Ms Cissé Oumou Traoré, Ms Coulibaly Salimata Sidibé, Ms Bore Fanta Guindo, Mamadou Soufountera, Ms Berthé Aïssata Bengaly, Ms Martine Samaké, Abdoulaye Djiré, Ms Yara Koreissi, Ms Tangara Adiaratou Sidibé, Mohamed Diarra, Kola Tangara, Moussa Daouda Sanogo, Michel Vaksmann (CIRAD/IER), Diakalia Sogodogo, Lamissa Diakité, Moctar Traoré, Alpha Oumar Kergna and the machine operator from Koutiala, El Hadj Moussa Traoré.

Oumar Niangado (former Director of IER and now delegate of the Syngenta Foundation), who was one of the first Malian researchers to take an interest in fonio.

Private sector partners: Ms Mariko Fadima Siby from Ucodal, Ms Deme Aïssata Thiam and Ms Dem Halatou from Danaya Céréales, Ms Soumaré Modia Sangaré, Ms Coulibaly Nanténé Coulibaly from Dado Production, Ms Coulibaly Aïda Diop, Ms Batoma Sacko, a.k.a "the River Lady" in Bamako, Ms. Tangara de Ségou and the many other fonio processors, as well as Singalé Soumaré from Grenier du Paysan in Kayes, as well as the equipment manufacturers Imaf (and in particular Adama Simpara and Arboncana Touré), SIpS (Abdou Kipsi Diop and Youssouf Abdoulaye Touré), Mod Engineering (Moussa Diarra), BCN (Baba Coulibaly Neto) and Stéphane Besançon from the international NGO Santé Diabète.

In Burkina Faso, Éric Vall, Augustin Kanwé, Ms Nadine Andrieu, researchers at CIRDES in Bobo Dioulasso, and Sansan Da from Inera in Bobo Dioulasso, as well as Brehima Diawara, Alhadi Wereme, Ignace Medah, Gouyahali Son and the teams from the Food Technology and Agricultural Mechanisation teams from IRSAT (Applied Sciences and Technology Research Institute) in Ouagadougou, in particular Ms Patricia Ouédraogo Zigani, Ms Charlotte Konkobo Yaméogo, Ms Laurencia Ouattara, Rachidi Karimou, Mathieu Kambou, Theodore Hiem, Stéphane Zangré, Antoine Crépin Kaboré, Nessan Bamissa Barro. Thanks also go to the fonio processors, including Ms Assétou Traoré Lingani (E^{ts} Tout Super), Ms Asséta Ouedraogo Bagguian (EOBA) from Ouagadougou, Ms. Korotoumou Traoré (Etrafils) and François Xavier Traoré (UTF) from Bobo Dioulasso and Philippe Ki, coordinator of the NGO Afrique Verte-Aprossa. And finally the equipment manufacturers Cyr Prosper Bary (SGGI), Mamadou Ouattara (Soldev), and the producers' representative Zakaria Kienou.

In Senegal, Cheikh M. Fadel Kébé, Ms Eve Dione, Mady Cissé, Vincent Sambou, Alkassoum A. Anne, Abdoul Diallo, Cheikhou Kane, Nicolas Ayessou, Ababacar Ndiaye, Ms Adji Madjiguene Sow, Ousmane Wane from ESP/UCAD, Alioune Fall and Papa Madiama Diop from ISRA, Babacar Touré, Ms Khanata Sokona, Ousmane Gueye, Ms Fatou Ndoye, Pape Seck

and their colleagues from the NGO Enda Graf, Ms Ndiaye Aïssatou from Koba Club in Kédougou and the fonio processors from Salémata (Eastern Senegal), Ms Aïssatou Diagne Deme from Free Work services in Dakar, the fonio processors from Kolda and Sanoussi Diakité.

In Benin, Jean Opala, fonio processor in Natitingou and Ms. Nadia Fanou Fogny, from the University Abomey Calavi near Cotonou.

In the Netherlands, Ms Inge Brouwer, from the University of Wageningen, Andrey Kuleshov, Project Manager at the Common Fund for Commodities (CFC) in Amsterdam.

In Belgium, Didier Stilmant, Brice Dupuis and their colleagues from CRAW (Wallonia Centre for Agronomic Research) in Libramont.

We would particularly like to pay tribute to the memory of our colleagues who disappeared in tragic circumstances: Doré Guindo, Director of the Sotuba IER Centre in Bamako, who coordinated the activities of the Malian teams working on the Fonio project funded by the European Union; Claude Marouzé and Jacques Brouat, from CIRAD Montpellier, who made a long-standing contribution to the design and development of fonio post-harvest equipment; Souraghata Kouyaté, an agricultural mechanic who participated in the development and distribution of fonio post-harvest equipment in Guinea; Romain Dossa, a teacher/researcher in nutrition from the University Abomey Calavi in Benin; Bakary Daho, a PhD student at CIRDES in Bobo Dioulasso (Burkina Faso). They will be remembered for their qualities of selflessness and dedication.

We would also like to thank everyone – producers, processors, employees, interns, traders, sales staff, consumers and decision makers – who devoted time answering the various surveys, or who took part in the various trials.

To all those we have mentioned, and any who might have been forgotten, we are truly grateful.

Finally, we would like to thank the people who have contributed to the publication of this work, and in particular Tristan Meudic for his drawings, our colleague Mamadou Billo Barry for writing the preface; our colleagues, Ms Geneviève Fliedel, Jean-Pascal Pichot and Michel Havard, who were kind enough to proofread the document; and for publishing purposes, James Brownlee, translator, Ms Emma Morton Saliou, proofreader, Ms Joëlle Delbrayère and Ms Hélène Bonnet, graphic designers; Editions Quæ, CTA & PAG for the assignment of publication rights of the book "Le fonio, une céréale africaine" and Philippe Lhoste, Director of the *Agricultures tropicales en poche* Collection.

Jean-François Cruz and Famoï Béavogui

Preface

It is with great pleasure that I accepted the invitation to write the preface to this work dedicated to fonio, which for me is an iconic cereal. In my youth, I grew it every year, with my parents, in Fouta-Djalon. Visiting the family field when the ears were emerging, to see the slender panicles sway in the wind, and smell its aroma, is one of my fondest memories. Fonio remains my favourite dish to this day.

As the authors point out, fonio *(Digitaria exilis* Stapf*)* is a little known cereal with small, coated grains, produced primarily in West Africa. It is primarily in Guinea, in Fouta-Djalon, that fonio is grown (approximately 60% of world production), since it is the staple food of the population. With exports going to Europe and the United States, fonio is now consumed beyond its production zone.

Scientific interest in this so-called "minor" plant is very recent. It was only in the 2000s that a multidisciplinary team of African and European researchers first took the initiative to conduct a broad-ranging study of the West African fonio industry. This team implemented two successive research projects, with the participation of various fonio industry players (farmers, processors, equipment manufacturers, traders, transporters, policy makers, etc.). These two "fonio" projects, funded by the Common Fund for Commodities, and then by the European Union, were conducted in Guinea, Mali, Burkina Faso, Senegal and Benin, with the participation of French, Belgian and Dutch researchers. Some of the participants in these two research projects decided to promote their work by publishing this book, which is the first dedicated exclusively to fonio. They also used other work and older articles to give readers a more precise and comprehensive picture of fonio, in all the aspects of the industry: the plant and its grain, the cultivation systems, cultivation techniques, production, processing, and trade, including export and consumption.

This work shows us that fonio is a traditional crop of the savannah tropical zones. It is grown in a wide variety of environmental conditions – everywhere except in water. Its particularity is its ability to thrive in poor soils where other cereals like rice or maize would struggle to grow. This ability to tolerate poor soils makes it a plant which, very often, comes only at the end of crop rotation cycles, after several years of growing more demanding plants like yam, rice or peanut. It may be the first rotation crop on soils which do not tolerate demanding crops, and run on a sequence of several years (from three to six years or more). It is also drought-resistant thanks

to its highly developed root system. This set of characteristics gives fonio a hardiness which means that marginal land can be exploited while safeguarding the environment. But the manual hulling of fonio, primarily carried out by women, is a tough activity.

Although its yield is relatively low — from 500 to 1,000 kg/ha — it offers nutritional characteristics prized by consumers. This is a tasty plant consumed in various forms: steamed or boiled couscous, gruel, tô, etc. In farming families it is considered to be a healthy food, since it is "light" in the stomach, not fattening and easy to digest. It is for these same reasons that it is often recommended for sick or convalescent patients. Fonio also has economic and social qualities. Hence it is sold for a higher price than other cereals. In addition, a fonio dish can be considered a dish of honour, since it is served only to important people (wise men, officials, religious dignitaries, parents-in-law, guests of honour, etc.) in important ceremonies (baptisms, weddings, funerals, etc.).

Finally, full credit goes to Jean-François Cruz and Famoï Béavogui for conducting a large-scale analytical summary work, leading to this document which reveals to the public the economic and social importance of fonio. Their work also sets out the challenges that lie ahead in terms of improving production, processing and fonio trade. It ends with specific proposals for research and action arising from knowledge acquired, and personal comments from these two authors, thereby enlightening decision makers and industry players. My wish for the publication of this work is to pave the way for the emergence of a strong fonio industry for the benefit of farmers and the other players involved. Other minor species await public recognition as well.

Conakry, 23 May 2011

Mamadou Billo Barry,

Scientific Director and Deputy Managing Director of the Guinea Agronomic Research Institute (IRAG)

Introduction

For ten thousand years, since the birth of agriculture, countless plants have been domesticated for feeding humans or animals, yet there are now only tens of species cultivated on a large scale worldwide. Among cereals, the most common species like rice, wheat and maize form the basis of the diet of a large part of humanity. Some species, often described as minor cereals, have been forgotten by "green" revolutions, despite playing a big role in the food security of some of the poorest populations. Well-suited to local edaphic and climatic conditions, they can withstand drought fairly well, and contribute to maintaining the environment, by ensuring plant coverage on ecologically fragile and under-exploited land.

One such traditional crop is fonio, a small-grained cereal which has long formed the staple food of many families in rural parts of West Africa, and which is now being rediscovered by urban consumers.

This document is the first work dedicated exclusively to fonio. Its purpose is to bring together in simple, sometimes non-technical terms, the information available on this cereal. Most of the data come from projects or research programmes that the authors have coordinated, or in which they have participated since the late 1990s, and particularly the projects "Improvement of fonio post-harvest technology" (1999-2004) funded by the CFC (Common Fund for Commodities), "Improving the quality and competitiveness of the fonio industry in West Africa" (2006-2008) funded by the European Union and "Improvement of post-harvest and enhancement of fonio in Africa" (2012-2016) funded by the African Union (10th European Development Fund, EuropeAid procedure). Older articles, published by researchers or travellers exploring West Africa, have also been used. The work provides a description of the fonio plant and grains, and provides information on various cultivation and production systems in various environments. It describes the main fonio traditional production and processing techniques, and it suggests possible avenues for improvement. Finally, it looks into ways to improve fonio exploitation, covering aspects relating to developing new products, trade and consumption. The text is divided into chapters covering these main fields. We ask our readers' forgiveness if they consider that a particular point has been glossed over, or another has been over-developed, but this will doubtless have something to do with our respective specialities in technology and crop science. The authors hope, above all, that this publication will help the various industry players, technicians and researchers, as well as new consumers or anyone simply wishing to expand their knowledge, to get to know this little African cereal better.

1. Origin and geographic distribution

Fonio *(Digitaria exilis* Stapf*)* is regarded as the oldest indigenous cereal in West Africa. The first references to fonio as a food are reported from the mid-14th Century by the Berber explorer Ibn Battûta in his "*Voyage to Sudan*" (modern-day Mali). He specified that, in these lands, *coscoçoû* (couscous) is prepared with *foûni* (fonio) "which is like mustard seeds", and adds strangely that "rice is harmful to Whites who eat it; fonio is better." In the 19th Century, in his "*Voyage to Timbuktu*", the French explorer René Caillé mentions fonio, which he describes as "*foigné*" (a small grass species). This was in April 1827, as he approached the foothills of Fouta-Djalon in the Télimélé region of Guinea. Then, as he progressed further inland, crossing the regions of Kankan, Ouassoulou, Odienné and Tingrela, he frequently reiterated that fonio forms one of the staple foods of the inhabitants, who prepare it as a gruel or in the form of *tau* (nowadays called "*tô*").

In 1905, L. Renoux and P. Dumas specified that fonio, along with rice, was the staple food of the population, and that "the early appearance of certain varieties remedies food shortages."

Closer to our times, in the 1950s, the famous French agronomist Roland Portères wrote a monograph dedicated to it. He noted, recalling the work of Germaine Dieterlen, a French Africanist ethnologist, fonio's importance in the cosmogony of the Dogon people in Mali, where it is regarded as the first and oldest cultivated grain. "It is the image of the original atom whence the universe sprang." This cereal also plays a significant role in other traditional African societies like the Bassari in Senegal, the Coniagui in Guinea or the Bêtamaribê (Otamari people) in northern Benin.

In 1894, the doctor André Rançon was amazed that fonio could be regarded as a variety of sorghum, and called it *Penicellaria spicata* Wild. Then in the early 20th Century, fonio was identified as *Paspalum longiflorum*; that is how it was called by L. Renoux and P. Dumas in 1905. In 1912, Henri Jumelle, in his article on colonial crops, specified that fonio precisely corresponds to *Digitaria exilis* Stapf according to Auguste Chevalier, the French botanist. In 1915, Otto Stapf believed that *Digitaria exilis,* to which he lent his name, is derived from the wild form *Digitaria longiflora*. He also revealed that Auguste Chevalier was the first to give the name fonio (bambara) to this plant in his report "A Mission to Senegal" in 1900 (Stapf, 1915). Primo-domestication

of fonio appears to date back to 5,000 BC (Purseglove, 1985), and the main domestication centre of fonio appears to be the central delta of the River Niger (Portères, 1976).

Fonio cultivation zones extend between the 8th and 14th North parallel, from the Senegal to Lake Chad. Further east, the secondary cereal cultivated is coracan *(Eleusine coracana)*. It is above all in Guinea, in the mountainous regions of Fouta-Djalon, that fonio represents one of the staple foods of the population. As figure 1.1 illustrates, it is also grown in Mali, Burkina Faso, in Côte d'Ivoire, Nigeria, Benin, Senegal, etc.

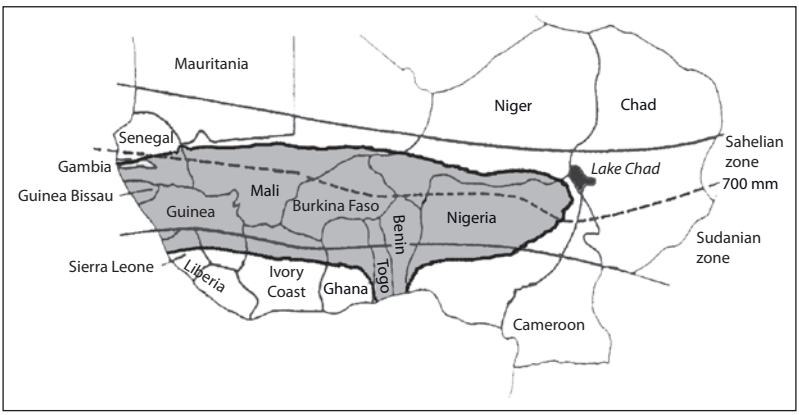


Figure 1.1. Cultivation zones of fonio *(Digitaria exilis)* (Cruz, 2001, according to R. Portères).

Outside Africa, fonio is grown in the Dominican Republic, where it was introduced in the 15th Century. Known by the name *funde*, it has been retained by farmers because of its good resistance to drought. It seems that it is now being rediscovered as a gourmet product, and is even claimed to have aphrodisiac properties (Morales-Payán *et al.,* 2002).

2. The plant and grain

In botanical terms, fonio is a glumaceous monocot of the grasses family (Gramineae or Poaceae) and the genus *Digitaria*. Crabgrasses, which encompass hundreds of species, are sometimes cultivated as fodder plants, and only three or four species are exploited for their grains.

Hence white fonio *(Digitaria exilis)* can be distinguished from black fonio *(Digitaria iburua)* in West Africa, hairy crabgrass *(Digitaria sanguinalis)* in Western Europe and raishan *(Digitaria cruciata)* in the Khasi mountains of north-east India. Today, only white fonio enjoys some degree of importance in West Africa. Its botanical name is *Digitaria exilis* (Kippist) Stapf. It is often considered to be one of the nine millet species (House, 1995), and is sometimes referred to as "crabgrass millet". English-speaking West Africa refers to it as "*hungry rice*" or *"acha*" and, locally, it is given a host of names varying between regions and ethnicities: *fundi, fini, foundé, foinye, ipoaga, ova, pon*, etc. In 1955, the agronomist Roland Portères, who studied vernacular generic names, concluded by saying that the terms for fonio all have the meaning "food", i.e. "something to eat".

Herbaceous plant

Fonio is a small annual herbaceous plant 30 to 80 cm in height, which has an inflorescence most often comprising two or three racemes or spikes (figure 2.1). The racemes bear spikelets grouped in twos (early varieties), threes or fours (late varieties) on pedicels (figures 2.2. and 2.3.). The spikelet has a sterile flower and a fertile flower which produces the fonio grain. The stubble, cylindrical and hollow, is very fine (less than 1 mm in diameter), and on maturity the stems lie on the soil. Fonio is a cereal which has good tillering (2 to 6 tillers, or more for late varieties).

The root system of fonio is highly developed, with many fine roots and abundant lateral rooting. The particular size of this root system, which can extend down to more than one metre in depth, helps explain the good behaviour of the plant during periods of drought, and its adaptation to poor soils, which it exploits efficiently.

The fonio species have great biodiversity and the many local varieties, or ecotypes, differ in colour and habit of the plant, colour and size of the grains, and more frequently in the length of the growth cycle (Diallo *et al.*, 2008). A distinction is commonly made between the extra-early varieties (70 to

90 days), the early varieties (90 and 110 days), semi-late (or intermediate) varieties (110 to 130 days) and late varieties (more than 130 days) vegetative growth. Collections exist for each country; one of them comprising more than 400 specimens is in France, at the Institute of Research for Development (IRD) in Montpellier.

Figure 2.1. Fonio plant (T. Meudic).

Figure 2.2. Raceme portion (T. Meudic).

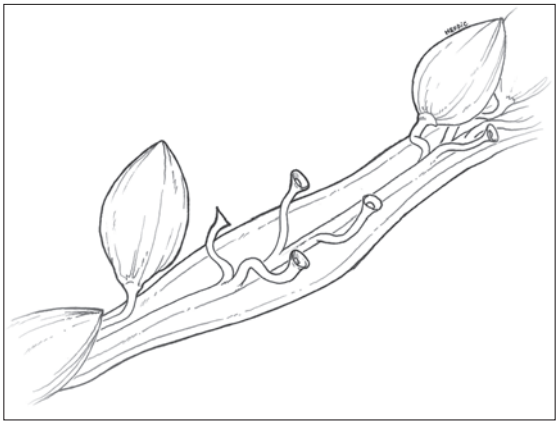


Figure 2.3. Pedicels grouped in 4s (T. Meudic).

In 1955, the agronomist Roland Portères suggested a distinction into five racial groups based on morphological characteristics:
– densa varieties: tall plants bearing 3 or 4 very long racemes (15-18 cm), where the pedicels are grouped in fours (120-140 spikelets per 10 cm). The grains are small and globular (2,100 grains per gram) and the plant is highly pigmented. Late varieties found in Togo under the name Semre or Sebre.
– rustica varieties: these are "big fonios" (foniba) bearing 2 or 3 racemes 9 to 12 cm in length, where the pedicels are grouped in fours (90-120 spikelets per 10 cm). Elliptical grains (1,750 to 1,800 grains per gram). Late varieties found in Guinea, Mali and Senegal under the names Foniba, Konso, Rané, Siragué, Kassambara, Tama.
– mixta varieties: 60 cm plants with fine straw, bearing 2 or 3 racemes 8 to 12 cm in length, where the pedicels are grouped in fours (90-120 spikelets per 10 cm). Grains plump to ellipsoid in shape (1,900 grains per gram),

with a white yellowish to pinkish pericarp. Semi-early varieties, generally coloured, found in Guinea under the names Saara, Moussogbé, Keleaningbé.
– stricta varieties: 40 to 65 cm small plants with very fine straw, often bearing 2 racemes 8 to 12 cm in length, where the pedicels are grouped in threes (60-110 spikelets per 10 cm). Ovoid, elongated grains, generally white (1,800 grains per gram) mainly over 1 row, except in the middle of the raceme. Early varieties found in Guinea, Mali and Senegal under the names Momo, Kouroukeleni, Peazo, etc. or even early white fonio.
– gracilis varieties: 50 to 60 cm plants with fine straw, often bearing 2 racemes 8 to 14 cm in length, where the pedicels are generally grouped in threes (80-90 spikelets per 10 cm). Ovoid grains (1,700 grains per gram) apparently in 2 rows. Early varieties found in Guinea, Mali and Senegal under the name Berele (or Bèrèlen).

Miniscule, dressed grains

Like rice, fonio is a so-called "dressed" cereal: after threshing, the grains retain a coating of glumes, lemma and palea, and so we talk about "paddy fonio" (see colour photo album). This is a terminological misuse, since the term "paddy" is normally reserved for rice, referring to dressed rice grains or "rice in husk". So out of similarity and sheer convenience, some engineers have adopted the habit of deeming non-hulled fonio grains "paddy fonio". These grains are very small in size, around one millimetre, and the weight of 1,000 grains is on average 0.5 g. A description of the physical and biochemical composition of the grains is given in chapter 5.

Compared to other well-known cereals, fonio grains are minuscule (see figure 2.4. and colour photo album), which makes them all the more difficult to process (hulling), and clean, since they are comparable in size to grains of sand.

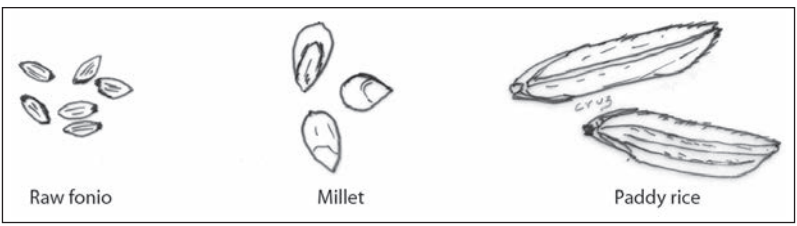


Figure 2.4. Grains of "paddy fonio" compared to millet and paddy rice.

Other names for "fonio"

"Black fonio" is a crop observed in 1911 by Dudgeon in Zaria, an area in Haoussa country in northern Nigeria, where it was called "iboru" by local populations (Stapf, 1915). This small cereal was described by Otto Stapf in 1915 and since then has borne the name Digitaria iburua Stapf. In 1946, Roland Portères wrote that the cultivation area of black fonio is located in the north-west area of the Bauchi plateaux in Nigeria (figure 2.5.) and in the southern foothills of the Atacora mountains straddling Togo and Dahomey (modern-day Benin). He specified that it is only in Togo that black fonio is cultivated in a pure state in the districts of Kandé, Kpessedé and Ataloté. This unpopular species is apparently difficult to hull, and used only for preparing the local beer, known as "tchapalo". It is also found in crop mixtures, with a few varieties of white fonio in Birni district, to the south of Natitingou (Benin), where it is used as a lean season food like white fonio.

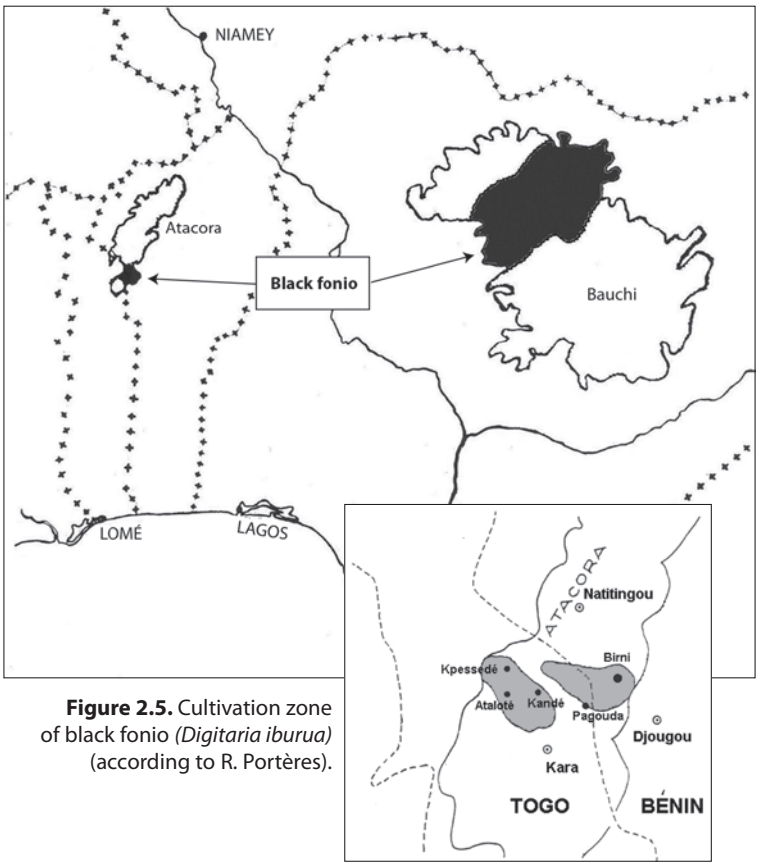


Figure 2.5. Cultivation zone of black fonio *(Digitaria iburua)* (according to R. Portères).

"Large grained fonio" is sometimes considered to be a fonio variety, though Portères defined it as a different species, *Brachiaria deflexa*. In its wild state, this small cereal is present in the sandy coastal savannah and in the Sudano-Sahelian zones, where it is known as a gathered millet. It seems that a variety is cultivated in the north of Fouta-Djalon in Guinea, in the Mali region at more than 1000 m in altitude, where growers call it "*founi kouli"* or "large grained fonio". Its grains are deemed to be more floury than white fonio, and the flour is used for preparing cakes and fritters (Portères, 1951). *Brachiaria deflexa* is sometimes called "animal fonio" (de Wet, 1995).

"Wild fonio" *(Panicum laetum),* commonly known as "haze", is an annual spontaneous grass, whose seeds are used as a gathered food by nomadic populations (Tamashek, Fula, etc.) of the northern regions of Mali, Burkina Faso and Niger (see below).

The term "fonio" is sometimes wrongly used to refer to other cereals. In Chad, coracan *(Eleusine coracana)* is very often called "fonio", and in the north of Cameroon, pearl millet *(Pennisetum glaucum)* is sometimes called fonio, while sorghum *(Sorghum vulgare)* is called millet. This clumsy error is also made by several authors like Dalziel (1937), or Baudet (1981), who described *Digitaria exilis* Stapf as "little millet".

3. Cultivation and production systems

Fonio is cultivated in West Africa in a tropical climate, with a well demarcated dry season, with average temperatures of 25 to 30 °C and an annual rainfall of 600 to 1,200 mm. Yet in Guinea, fonio is also present in mountainous zones where the altitude is in excess of 1,000 m with a higher rainfall (1,500 to 2,000 mm), and distinctly cooler temperatures (15 to 25 °C during the growing season).

Characteristics of some fonio cultivation zones

The main examples described are found in French-speaking countries.

Main fonio production zones in Guinea

Fouta-Djalon in Middle Guinea, a land specialised in fonio cultivation

In Guinea, fonio is produced in the four natural regions, but is grown the most in Middle and Upper Guinea, where it is the number two crop after rice (Diallo, 2003). In these regions it is both a staple and a lean season food, before the harvests of other crops.

In Middle Guinea, fonio covers a large part of Fouta-Djalon (figure 3.1). This sandstone mountain range comprises high, long tabular plateaux running from south to north, from Dalaba to Mali, at an altitude of approximately 1,000 m, and up to 1,425 m at Mount Diaguissa near Dalaba and 1,538 m at Mount Loura near Mali. These plateaux are scored with numerous more or less steep valleys, the main ones being Kokoulo, Kakrima and Téné, which separate the whole range into three main sub-ranges (Dalaba, Labé, Mali), as figure 3.2 shows. To the east, the plateau is less high (700 to 900 m) and extends to the edge of Upper Guinea; to the west, the mountains turn into extensive grasslands, divided by gallery forests.

The climate is Sudano-Guinean, with two very distinct seasons. Yet, modified by altitude, it is described as a Guinean-Foutanian mountain climate. The rainy season, which lasts five months from May to October, brings monsoon rains from the ocean. Fouta-Djalon, which receives 1,500 to 2,000 mm of rain per year, is often referred to as the "water tower of West Africa", since

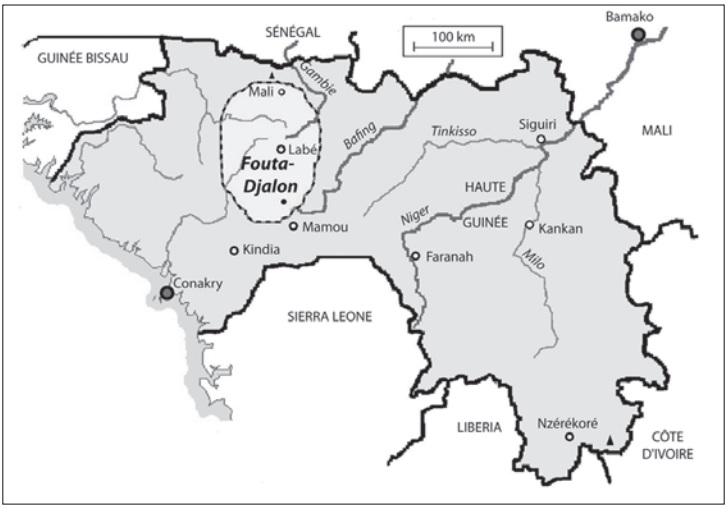


Figure 3.1. Fouta-Djalon region in Guinea.

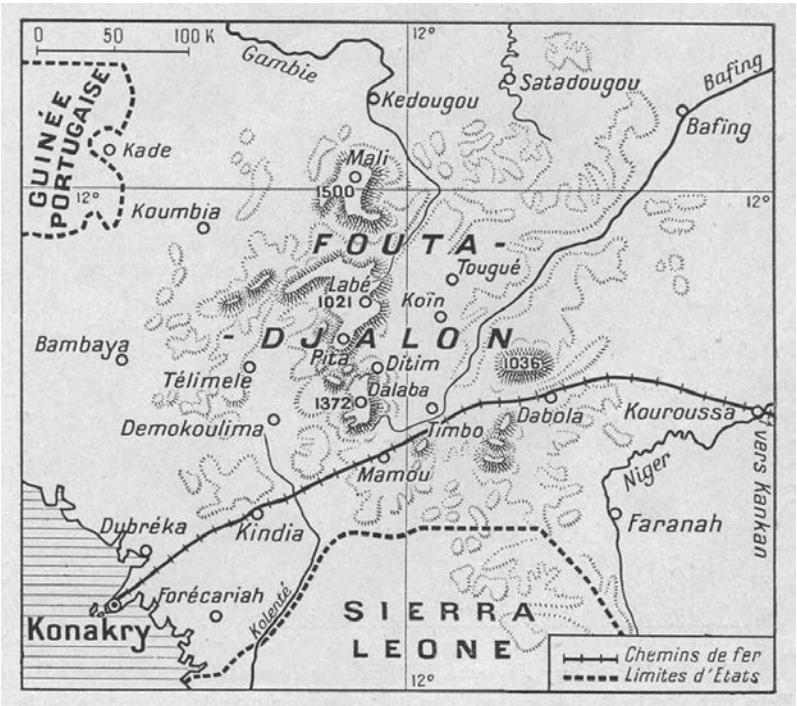


Figure 3.2. Old map of Fouta-Djalon (Balachowsky, 1954).

many rivers such as the Gambia, the Bafing (which becomes the Senegal), the Tominé or Corubal and the Tinkisso, a major tributary of the Niger, spring from there. The dry season, from November to April, is subject to the influence of the Harmattan, a hot, dry wind from the Sahara, but the altitude of Fouta mitigates the aridity of this season thanks to the night and morning mists which cloak the mountains. Mean monthly temperatures do not exceed 25 °C, and the climate of Fouta-Djalon, temperate and cool, is often deemed very pleasant.

The soils are generally poor in minerals. The long weathering of sandstones and schists has given rise to ferralitic soils. In the Timbi Madina zones west of Labé, we can distinguish *dantari*, a dry plain soil with herbaceous vegetation, which is a light coloured ferralitic clay-sand soil poor in organic matter, often dedicated to fonio cultivation, and *hollandé,* a piedmont or plain soil, which is a dark coloured ferralitic clay-silt soil, on which rice is usually grown.

The slope soils or *hansanghéré,* which are red, stony ferralitic soils bearing bushy vegetation, are derived from the weathering of hard lateritic crusts. These filtering soils have a structure facilitating deep root development. Said to be more fertile, they are sought-after for cultivating cereals, and in particular fonio. Downstream of the slopes, we can find stream inland valley soils, which are seasonally hydromorphic clay-silt soils, known as *dunkiré*. They are used to grow above all potatoes, rice, maize or peanuts, which make up most of the revenue of farming households. Finally the plateau, when the run-off has carried away the fine soil elements, is left with the *bowé,* comprising a skeletal soil on hard lateritic crust, on which a few trees grow, and in the rainy season, some grasses which can be used for pasturing. The sequence of the various soil types is illustrated in figure 3.3.

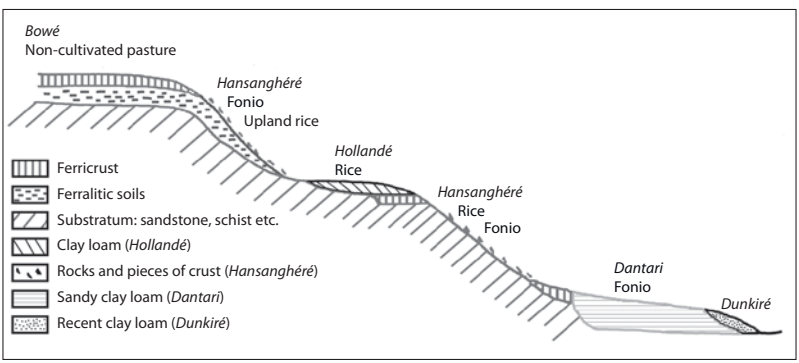


Figure 3.3. Relative position of the various soil types (according to J.M. Garreau, 1993).

This whole region, with a majority Fula population and some Mandinka populations (Dialonké, Soussou, Malinké, etc.), is dedicated to livestock and food crop farming. The lack of good quality soil resources explains why fonio, a very undemanding crop capable of exploiting the last elements from the soil, is so predominant. Many agronomists have long asserted that fonio was responsible for soil depletion (Sudres, 1947), but it is certainly fairer to believe that local populations grow fonio because it is the only crop possible on very poor land.

In Fouta-Djalon, the toposequence structures cultivation systems, with the main ones being "*tapades*", outfields and stream inland valleys. A tapade is an enclosure in which a family unit lives, and makes up the bulk of the smallholding. Previously, the term *tapade* described only the fence (live or mixed hedge) protecting this enclosure, known as a *"gallé"*, from grazing by livestock. The tapade is divided into cultivated plots *(sountouré)*, without fallow land, by the women, who each have an individual homestead. This is intensive cultivation (in terms of ploughing and fertility transfer), which combines various species such as maize, cultivated near the homesteads and sometimes associated with cowpea, sweet potato, peanut, cassava, potato, onion, tomato, aubergine and with various sauce-making plants such as gumbo, roselle and peppers. There are also many fruit trees such as mango trees, orange trees, banana trees and some avocado trees, or even certain trees cultivated for making rods or for dyeing (true indigo). Fonio can sometimes be cultivated in tapades, but in this case it will be in the most marginal peripheral areas, the least amended, or areas recently incorporated in the tapade.

The second traditional cultivation system is so-called "outfields", which are at a varying distance from the tapades, and generally dedicated to extensive cultivation of fonio in rotation with dry-land rice, peanut or cassava. But most frequently, fonio is grown in successive years. It is a traditional cultivation system, where the work is still managed collectively, in particular on land well away from the village. It produces low yields, often less than 800 kg/ha for fonio, because of the poor soils and absence of fertilisation. Indeed, input of organic matter (cow pats, dung, crop residue) or minerals (ash) is reserved for tapade plots and stream inland valley cultivation. While tapade cultivation remains the domain of women, outfield cultivation is the work of men, who prepare the land by clearing and burning. Women and children however are involved in production, participating in the sowing and weeding operations, and taking an active part in the harvests. The crop is grown on open outfields for a few years, then the land is left to rest for a fallow period of varying length. In plain areas on *dantari* or *hollandé* soil, fonio is cultivated year-on-year, for four to six years, followed by a fallow

period of equal duration. In sloped areas or *hansanghéré*, the cultivation period is shorter (two to four years), and the fallow period is longer. Hence rice can be grown for two years, followed by fonio for two years, and then a fallow period of seven to nine years. In 1949, the rotation was described as follows: rice, rice, fonio and peanut (with the field divided into uneven blocks), fonio and peanut or fonio only, cassava, fallow (Guillaume *et al.,* 1949). If the need for cultivable land increases, the fallow period can sometimes be reduced, though it may increase if, at village level, the workforce is reduced for reasons of young men emigrating.

Finally, the third cultivation system is stream inland valley cultivation on *dunkiré* soil, practiced since the colonial era. These seasonally hydromorphic alluvial zones, with a clay-silt texture, have been exploited this way for many years for growing food crops (rice, maize, etc.). Yet space is limited in the stream inland valleys, and attempts are often made to maximise its value through market gardening in the dry season, in particular the potato, which plays a key role and which, in some places, brings in the bulk of revenue for the farms. As with tapades, soil fertility improvement of stream inland valleys is primarily due to the work of the women. Wood ash input increases the richness in macronutrients (calcium, potassium, magnesium), and reduces soil acidity. In tapades and stream inland valleys the pH is relatively balanced, whereas it is acidic in the *dantari* or *hollandé* soils of outfields. Fonio is never grown in stream inland valleys.

Fouta-Djalon is the main fonio producing region in West Africa. The Labé region alone produces more than 100,000 t of fonio, i.e. nearly half of the national production in Guinea, and nearly one-third of the total production in West Africa (table 3.1).

Table 3.1. Fonio production, by region, in Guinea in 2006 (rounded data).

Region	Boké	Kindia	Labé	Mamou	Faranah	Kankan	Nzérékoré	Total
Production (t)	15,000	12,000	105,000	34,000	26,000	20,000	6,000	218,000

Source: National Agricultural Statistics Service, Ministry for Crop and Livestock Farming, Guinea

Upper Guinea, an area of savannah and flood plains

Upper Guinea, which covers approximately 41% of Guinea, is situated to the east of Fouta-Djalon, and extends to the Malian border. Divided into two administrative regions (Kankan and Faranah), it corresponds overall to the Upper Niger basin. From the rugged high plateaux of Fouta-Djalon, the relief descends sharply to a lower plateau which is inclined gently toward the north-east, the altitudes of which are between 300 and 500 m (figure 3.4).

The River Niger and its tributaries such as the Tinkisso on the left bank, and the Milo and Niandan on the right bank, have carved flood plains into this upland basin, which are subject to flooding and bordered by a system of terraces. This region is influenced by the tropical South-Sudanian climate characterised by the alternation between the rainy season from May to

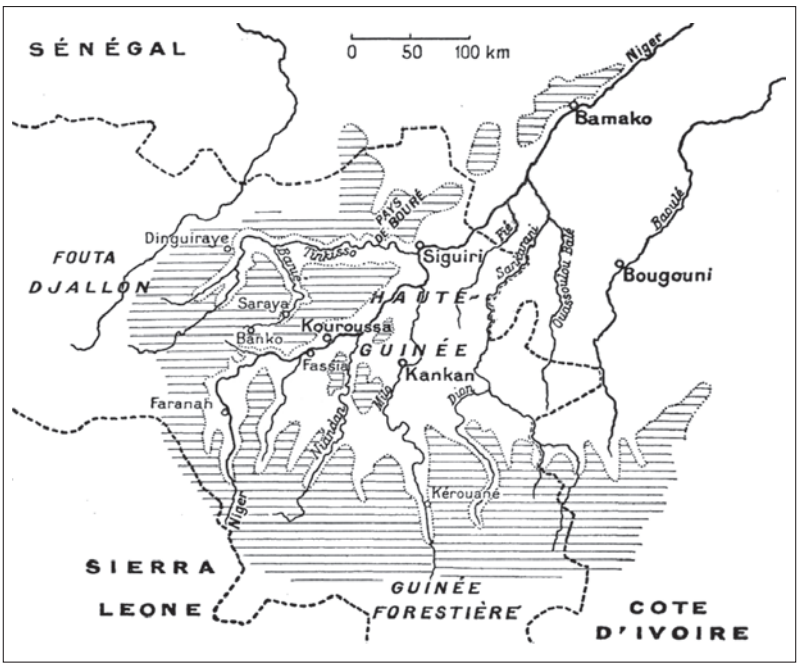


Figure 3.4. Old map of Upper Guinea (Gallais, 1959).
The horizontal grey shading corresponds to mountain areas in excess of 500 m.

"Large-grained fonio" *(Brachiaria deflexa)*

Fouta-Djalon appears to be the only place where "large-grained fonio" is cultivated as a food cereal. In 1951, Roland Portères reported that cultivation zones of this fonio were identified in 1938 by A. Sudres in the Labé region, at around 1,000 m in altitude, and then in the Mali zone between 1,000 and 1,200 m, and that he himself took a sample from the granary of a Malian farmer. This large-grained fonio (or *founi-kouli* in the foulah language) has a short cycle (70 to 75 d), and is sown only in August, long after "true" fonio, on hillside land which is richer and better drained. The plant, similar to dry-land rice, can reach a height of 1 m, and its grain yields reportedly exceed those of fonio cultivated under the same conditions. Its grains, less vitreous than fonio grains, produce a flour used for preparing cakes or fritters.

October, and a dry season from November to April, with easterly winds predominating (Harmattan). The annual rainfall of 1,200 mm to 1,700 mm is less than that of Fouta-Djalon, making Upper Guinea a region of grassy and arboreal savannah, and scattered forests.

The population, mainly comprising Malinké, is still primarily rural, with its density, much lower than in Fouta-Djalon, not exceeding 30 inhabitants per km^2. The main activities are agricultural, involving food crop farming and livestock farming, but also fruit arboriculture and market gardening. Mango trees are often planted on the high alluvial terraces and slopes, whereas cultivation of the cashew hedge, recently introduced to the plateaux, is still limited. Extra-agricultural activities involve trade, craft, fishing, hunting, gathering and, in places, traditional alluvial digging. Fruits from big savannah trees like the locust bean tree *(Parkia biglobosa)* and shea tree *(Vitellaria paradoxa)* are traditionally processed by women, into *soumbala* and shea butter respectively, and sold on the local markets.

The wet plains of the basins of the Niger and its tributaries are highly favourable for rice paddies, whereas the higher plain areas near the villages are sometimes dedicated to market gardening, carried out by the women and intended for sale.

On the plateaux and slopes, shifting slash-and-burn agriculture is the most common production method, because of the low population density and the lack of equipment on farms. In Upper Guinea, fonio still represents an important food crop after dry-land rice and plain rice, along with maize, sorghum, millet, peanut and cassava. Figure 3.5, which illustrates the standard toposequence in Upper Guinea in 1959, is still mainly applicable, although some of the varieties indicated may have changed. Today, the regions of Kankan and Faranah contribute more than 20% of national fonio production (table 3.1).

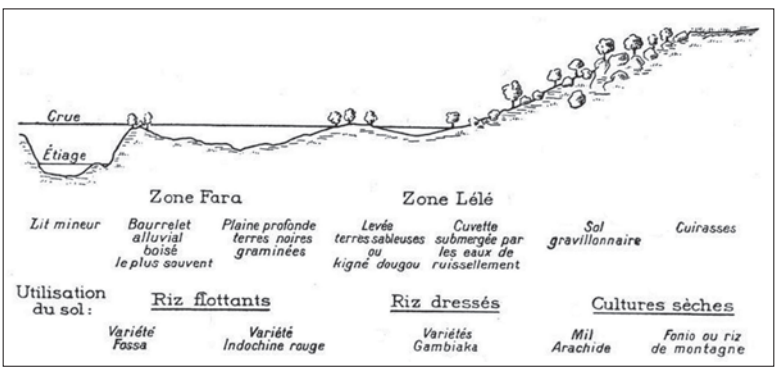


Figure 3.5. Soil use on the flood plain of the Upper Niger in 1959 (Gallais, 1959).

Fonio is generally cultivated after one or two years of dry-land rice, maize and sometimes peanut, and is most often succeeded by cassava. In this way, fonio can take advantage of a prior legume crop (peanut) for better yields. Then the fonio straw can be used as mulching for the cassava lists. Crop rotations are then followed by a relatively long fallow period, often in excess of ten years (Bourdillat, 1995).

The farmers rotate the crops on the plots until the soil is highly depleted. This depletion is often revealed by the presence of a parasitic plant like striga *(Striga hermonthica)*. Its appearance is generally due to poor soils, resulting from excessive periods of cereal monoculture and from the absence of inputs (manure, compost or fertiliser). The fall in fertility of the environment is sometimes due to nematodes, but fonio does not seem to be sensitive to these root parasite worms, and certain researchers have even suggested using fonio in rotation with market garden crops for the purpose of controlling nematodes of the genus *Meloidogyne* (Sarr and Prot, 1985).

With depletion of the soils, yam and dry-land rice cultivation are sometimes abandoned in favour of cassava grown in rotation with fonio. In certain cases, this rotation incorporates legumes like peanut, cowpea or voandzou. Fonio is only grown as the first rotation crop when the producers apply a monoculture system over several years, with very short fallow periods, but this scenario is fairly rare (Bourdillat, 1995).

Fonio is sometimes cultivated together with another plant. In Upper Guinea, the most common association is with another cereal like sorghum or millet, and occasionally with roselle *(Hibiscus sabdariffa* L.*)*.

Certain producers are able to fit two fonio campaigns into the same year, on the same plot, or more frequently on two different plots (Béavogui *et al.,* 1992). For the first campaign, they sow an "early" variety in May or June, when the first rains arrive. Thanks to its short 75-day cycle, this fast-growing fonio is harvested in July or August. While this first harvest is generally not very productive, it nonetheless feeds families during the so-called "lean season", pending the harvests of the other cereals (rice, maize, sorghum), which rarely begin before the end of September. The second campaign is sown with varieties that have cycles of varying duration, which are harvested beginning in October. The grains of these later and more productive varieties are then stored as reserves, and are consumed over the year or sold in part, depending on the families' needs.

Some fonio growing regions in Mali

In west Mali, a first production zone is located near Kéniéba in the south of the Kayes region, bordering Senegal and Guinea. In this region of Bambouk,

where the plain of the River Falémé suddenly gives way to the high cliffs of Tambaoura, agroclimatic conditions are relatively favourable, though in this region agriculture must often compete with gold mining. Agricultural activities remain focused on crop production, and for the Malinké populations fonio is a traditional crop in rotation with sorghum, millet, dry-land rice or peanut. In the north-east of this zone, in Kaarta, the northern limit of fonio cultivation lies just below that of millet and sorghum, on an isohyet of 600 mm. The Sarakolé ethnic group populating this region bordering Mauritania does not have a tradition of farming, and the few fonio crops encountered are located in Bambara villages, where fonio remains a choice dish.

In Mali, the main fonio cultivation area is south of the River Niger, in a triangle linking Bamako-Sikasso-Mopti (figure 3.6). Fonio production is primarily concentrated in the Ségou region around the city of San, with Tominian as a major centre, but also in the south-west of the Sikasso region near Bougouni, and in particular in the rural districts of Garalo and Kolondiéba. Further east, in the Mopti region, fonio is also grown in Dogon country on the Seno plain near Burkina Faso, particularly in the Bankass circle. These regions, watered by the River Niger and the River Bani, have a two-season Sudanian to Sudano-Sahelian climate (annual isohyets between 1,300 and 600 mm), and form a large crop production zone. Sorghum, maize, rice, millet and peanut are the most familiar crops, followed by cowpea, voandzou (ground nut or bambara nut) and fonio. These plants are cultivated across the zone and consumed in various forms. The legumes are considered useful for their capacity to improve soil fertility and their potential as feed. Their high protein content makes them very important nutritional resources. All these savannah zones from the Upper Niger valley to the central delta are considered by certain agronomists to be diversification sites for a host of cereals such as fonio, African rice and certain strains of millet or sorghum (Havinden, 1970).

In the zone of San and Tominian, crops like millet and fonio are grown on sandy soils, whereas sorghum is grown in places on more clayey soils. With annual precipitation ranging from 700 to 800 mm, the San region is unfavourable for growing maize, which is generally grown in the southern areas. This San zone, bordering the cotton zone, is characterised by a majority of farms with little or moderate amounts of equipment, managing small cattle herds. Since the 1970s, the cultivation period on the same plot has increased. Traditional systems, with cultivation periods of four to five years alternating with a fallow period of fifteen to twenty years, have developed into shifting cultivation systems of eight to ten years, or even practically continuous cultivation systems (nearly thirty years), which make fallow land available, thereby enabling an increase in cultivated surface areas (Gigou *et al.,* 2004).

Figure 3.6. Main fonio production zones in Mali.

The surface areas sown with fonio are not declining, and demonstrate the interest of farmers in this cereal. Yet yields are often variable, fluctuating between 500 and 1,000 kg/ha depending on the circumstances. Fonio production in five regions of Mali is set out in table 3.2.

Table 3.2. Fonio production in five regions of Mali in 2006.

Characteristics of fonio cultivation	Kayes	Koulikoro (Bamako)	Sikasso	Ségou	Mopti	Total for Mali
Surface area (ha)	6,820	910	13,120	12,180	12,740	45,770
Production (t)	4,860	680	7,770	9,140	3,800	26,250
Yield (t/ha)	0.71	0.75	0.59	0.75	0.3	0.57

Source: Planning and Statistics Unit, Mali Ministry for Agriculture

In the less populated Bougouni region, the economy is predominantly agricultural. The main cash crops farmed are cotton, peanut, market gardening crops and fruits, whereas the food crops are maize, millet, sorghum, fonio and cowpea. Yields of local cereal crops are relatively low, and sorghum and fonio crops are marginalised on the poorest soils. Fonio is generally cultivated at the end of the rotation, and preferably after a legume like peanut. The farmers are tending to replace sorghum with maize, since they consider that this cereal makes the best use of the carryover of the fertilisation of the cotton trees. Women often grow fonio to cover the financial needs of the family, but they sometimes have trouble finding outlets on the local markets. They also trade in processed gathered produce like *soumbala*, from néré, and

shea butter. Because of the heavy nature of the field work, a woman cultivating a fonio plot is a sign of courage often hailed and respected by the village community (Vall *et al.,* 2007).

On the Séno plain (which in the Fula language means "sandy") at the foot of the Cliff of Bandiagara, fonio is cultivated in rotation with millet, which occupies most of the cultivated land, whereas further south toward the border with Burkina Faso, it is sorghum or rice which are grown more, in the Upper Sourou valley. The agricultural systems always combine crop and livestock farming. Farmers make use of fields near the village, which receive organic amendments (manure and household waste), and fields away from the village, known as "outfields", which are left fallow after a few years in cultivation. Farmers leave in their fields certain big savannah trees such as shea, néré and balanzas *(Acacia albida)*. Some average crop yields obtained in the village of Lagassagou in 2000 are recapped in table 3.3.

Table 3.3. Average yields obtained in the village of Lagassagou (Mopti region).

Field type	Crop	Average yield (kg/ha)
Bush field	Millet	80
	Peanut	1,100
	Cowpea (interspaced with millet)	450
	Fonio	800
Field near the village	Millet	1,050

Source: Samaké, 2003

Fonio cultivation in Dogon country

In 1940, the French anthropologist Denise Paulme described the particular attention devoted by the Dogon people (Mali) to crops, and in particular fonio: "Fonio is broadcast sown, and requires only one weeding, approximately one month after the seeds have emerged [...]. While the earth carries out its slow work, the seeds germinate, the stems grow and the spikes form, the granary reserves, from where the grain has to be drawn for everyday meals, seem to diminish more quickly every day. Can the ever-present threat of famine be averted? [...] There are many sayings showing the care with which man follows the growth of the plants which underpin his subsistence. Fonio stems (in quick-growing varieties) start to emerge in the tenth month (August); their slenderness at this time invites comparison to needles: *menene duba*, they say, "We've made needles". The spikes quickly thicken, from the beginning of the eleventh month: "The fonio is pregnant", *pô bere*. Finally, the growers can make the joyous announcement to the village: *pô purai*, "The fonio is out, it is ripe". Famine has been avoided once more this year; from this point on, the fonio can be harvested."

Fonio zones in south-western and western Burkina Faso

In Burkina Faso, fonio occupies fifth position in the ranking of cultivated cereals, abundantly represented by sorghum and millet, followed by maize and rice. Since it represents less than 1% of total cereal production, it is considered a secondary cereal, but it still retains the very positive image of a traditional, high quality food, one highly rated by the populations who cultivate it (Bobo, Senoufo, etc.).

Fonio is mainly produced in the south-west of Burkina Faso, in the provinces of Kénédougou, Houet or Comoé, and in the west in the more northern provinces of Banwa and Kossi, along the Malian border (figure 3.7.). Depending on the year, fonio production in Burkina Faso varies from 10,000 to 20,000 t, with average yields of 600 to 800 kg/ha. Yet there are great disparities between the subhumid zones and more arid zones.

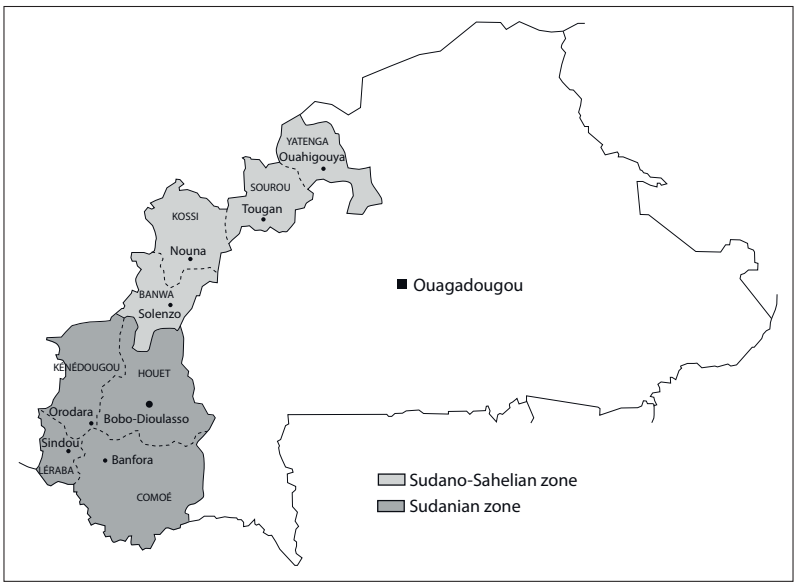


Figure 3.7. Fonio production zones in Burkina Faso.

Fonio from the Kénédougou-Houet subhumid zones

The Kénédougou-Houet regions correspond to the upper basins of the River Mouhoun (formerly Black Volta), which descends from the sandstone range of the Cliff of Banfora. The relief comprises plateaux and subhumid plains where rainfall of more than 900 mm per year is not a limiting factor, but where the tropical ferruginous soils are relatively poor. The Sudanian

vegetation is characterised by significant development of ligneous species, forming wild woody savannahs and gallery forests along rivers and streams. The natural conditions of these regions support a highly diverse agriculture, mainly dominated by arboriculture and in particular citruses and mango trees (Vall *et al.,* 2007). Thus Kénédougou province is sometimes known as the orchard of Burkina Faso. Food crop production is also significant, particularly of cereals (maize, sorghum, and millet). Fonio is present across the province and in particular in the Peni and Toussiana zones south of Bobo Dioulasso, and in the Orodara region, where it has approximately a 20% share in the cropping plan. Fonio is never the first rotation crop, as on an excessively rich soil, the grain/straw ratio is unfavourable to grain, and vegetation is too luxuriant (Stilmant and Dupuis, 2007). These regions of south-western Burkina Faso also produce legumes (cowpea, peanut), and roots and tubers (yams, cassava). Cotton remains one of the main cash crops, and contributes to the monetary revenue of farming households. Market gardening is another profitable activity. Finally, livestock farming is seeing remarkable growth, with recognised social and economic importance.

In this part of Burkina Faso, certain fonio plots are managed exclusively by women. When the fonio fields in the production unit are relatively large, sometimes in excess of 2 ha, the women, who are generally under-equipped with agricultural equipment and draught animals, must hire ploughing equipment. They must also call in external labour for harvesting and threshing operations, which involve heavy expenditure (Vall *et al.,* 2007). The women derive income by selling some of their fonio production, when the prices are at their highest, during the lean season between May and July.

Fonio in the semi-arid zones of Kossi

The Kossi region bordering Mali is the southern extension of the Malian region of Séno-Gondo, up to the north of Bobo country. This zone comprises a vast sandy plain with a few hills or berms to the west. It is subjected to a semi-arid Sudano-Sahelian climate, in which the annual rainfall, which varies irregularly between 600 and 800 mm, prevents significant crop diversification. Hence agriculture is dominated by traditional cereals like sorghum, millet and fonio, which represent the staple food crops. Other crops like legumes (cowpea, peanut, voandzou) or maize supplement household dietary needs. Cash crops are limited to sesame and cotton, though the surpluses of certain food crops like fonio can be sold to provide additional revenue for households (Vall *et al.,* 2007).

In these semi-arid zones which extend from Nouna, the province's capital, to Djibasso in the west and the banks of the Sourou in the east, the farms

are bigger (1.7 ha per agricultural worker) than in the other zones described above (on average 1 ha per agricultural worker). This development is enabled by a better level of mechanisation (draught cultivation), and a need to better adapt to the risk of rainfall shortage (Vall *et al.,* 2007). As in the neighbouring Malian regions of Séno and San, fonio occupies no more than 20% of the cropping plan, and is often inserted between two millet or sorghum croppings. Producers generally retain three sorts of fonio varieties: a short cycle variety, an intermediate cycle variety and a long cycle variety, although one of them is sometimes dominant. Because of the erratic nature of the rains, producers from the semi-arid zones often sow early short-cycle variety(ies), which are able to feed the families pending the other harvests. Hence fonio plays an essential role as a lean season food, mitigating for a certain period the absence of millet and sorghum in the granaries. Yet today some producers also want to harness it as a cash crop, as attested by the "fonio fair" organised every February in the village of Bomborokuy 40 km north of Nouna.

Fonio in other West African countries

Fonio, a traditional crop in eastern Senegal and Upper Casamance

In Senegal, fonio is cultivated in the south and south-east of the country, in the regions of eastern Senegal (from Koungheul, Koussanar to Kédougou) and Upper Casamance (from Sédhiou to Vélingara). It is above all in the Department of Kédougou that it is produced by the Jalonké and Bassari ethnic groups, in the foothills of Fouta-Djalon. The surface areas cultivated vary from 0.25 to 1 ha per family smallholding, and yields are around 600 to 800 kg/ha (Dramé and Cruz, 2002). The smallest surface areas are cultivated by women, who are increasingly seeking to harness fonio as a cash crop. Elsewhere, because of the lack of processing equipment, fonio has gradually been abandoned to be replaced by other products such as maize or market garden crops. In many villages, fonio is now just a crop intended for self-consumption, and very often maintained simply for traditional practices or ceremonies (festive periods, worship, and traditional medicine). This previously abundant cereal has now become so marginal that it barely figures in the agricultural statistics, which nonetheless evaluate current production at between 1,000 and 1,500 tonnes.

The few varieties conserved are often short-cycle (Momo or Yaoko variety) or intermediate cycle (Dibong or Mora variety), cultivated as lean season cereals for the purposes of self-consumption by households, pending the harvest of other cereals. Semi-late varieties (Rané or Findiba) are rarer, and late varieties are gradually disappearing (USAID, 2008). This product has a small market presence, since many producers take the view that "fonio is a festive product,

and shouldn't be grown to be sold." However, in certain zones of Senegal, such as in Koussanar, Kolda, Sédhiou or Kédougou, women's associations or village groups, often supported by NGOs, are aiming to re-launch fonio growing for commercial purposes. This is currently being boosted by the distribution of new high-performance machines which facilitate post-harvest operations. Thus they need to try to restore certain late varieties, which have sometimes disappeared from villages, and sell their produce on regular markets.

Fonio as a piedmont plain crop in Atakora, Benin

In Benin, fonio is produced in the Natitingou region, the administrative centre of Atakora Department, situated in the north-west of the country. It is a zone of low mountains (the highest peak in the Atakora chain is at 658 m) with a Sudano-Guinean climate, and a wet season from June to October which gives an average annual rainfall of 1,000 to 1,300 mm. This region, which has big tourism potential because of its Somba architectural heritage, has a primarily agricultural economy. It produces millet, sorghum, cowpea, yam, cassava, peanut and more recently maize and cotton. Rice is cultivated in certain stream inland valleys, and fonio is still present in some zones of Atakora, though it seems to be in constant decline since the introduction of early varieties of maize. The laboriousness of fonio processing operations is one of the main reasons for its gradual abandonment. The Boukoumbé Sub-Prefecture alone is responsible for the bulk of the region's production, i.e. approximately 1,500 t for 2,500 ha cultivated, with average yields of around 600 kg/ha. In this piedmont plain zone, close to the Togolese border, fonio still represents more than 20 % of cultivated surface zones, as it retains big socio-cultural importance for certain Somba ethnic groups, like the Otammari people. Although, like millet, sorghum and rice, fonio represents for them a grain for "male" consumption, women are very heavily involved in its cultivation, and even more so in post-harvest operations.

As in most of the production zones, the producers in the village of Kouya, close to the Togolese border, report using three types of varieties, with different cultivation cycle durations: an early variety known as Kouatnanfa; an intermediate variety Ipordawan; and a late variety, Ipo n'kouani or "flaking fonio", which is difficult to hull, but which gives a very white fonio. Another variety, Ikantoni, which is extra-early, is less frequent. These different varieties, harvested at different periods between August and September, are always stored separately. Fonio, known as "*ipoaga*" in the Ditamari language, is in large part aimed at self-consumption, and even today is still regarded as a lean season cereal. Hence the market supply is scattered and relatively small, since there are no real trade circuits.

Fonio in north-west Côte d'Ivoire

In Côte d'Ivoire, fonio is primarily grown in the north-west of the country in the regions of Odienné, Touba and Tengrela, and on the borders with Guinea and Mali. These savannah zones with a tropical Sudanian climate have only one rainy season from June to October, while between December and February they are subjected to the Harmattan, a dry and dusty wind from the Sahara. These regions are primarily agricultural, with a preponderance of cereal food crops like maize, rice, sorghum and millet. Yam is less common than in the more southern zones. Cashew and cotton are the main cash crops. Fonio is a secondary crop, which because of its hardiness and suitability for poor soils, has been retained over time despite relatively low yields of 600 to 800 kg/ha. The data are often incomplete, but national production is generally estimated at approximately 14,000 t for 20,000 ha. Fonio is consumed in the form of *tô*, but also couscous in peanut sauce, or cooked in fat like rice to prepare the traditional dish known as "*fesro*" (Aboua *et al.,* 1989).

Historically, the first reference to fonio in the Odienné region was made by the traveller René Caillé. When he left the village of Manégnan (now called Maninian) and arrived on 26 July 1827 at the village of Tangourouman, the inhabitants offered him for dinner "a dish of *foigné* with a herb sauce." Later, during an enforced stay in Timé (Tiéme) for five months to recuperate, he noted that fonio was a common food for the local population: "The Mandingos from this part of Africa […] have everything necessary for life: yams, maize, rice, millet, *foigné*, beans, squashes and *pistaches* grow in abundance in this fortunate country […]."

He explained that "*foigné*, which is sown in May, is harvested in July," and consumed in the form of tô, providing a description of its processing: "The women take great pains to clean it; they expose this grain to the sun, then they grind it using a pestle and mortar, separating the straw, which takes a long time and a lot of work; then, to extract the bran, they use a "*layot*" as in Senegal; they grind it a second time; and when the grain has been properly cleaned it becomes plump and white, like gunpowder grains; they then wash it and put it in a basket for it to drip dry, and leave it to rest to swell up a bit; finally, they put it back into a mortar, and a little pounding with the pestle is all it takes to reduce it to flour: if it is not wet, the grinding process takes much longer. With this flour they make a gruel which they call "*tau*" […]. When this gruel is cooked, it is spooned into a gourd, and seasoned with a sauce made from squash leaves and a quantity of other herbs, pepper and finally a little gumbo to make it sticky: this sauce never contains any salt or butter." (Caillé, 1830).

The special case of "wild fonio"

"Wild fonio" *(Panicum laetum* Kunth), commonly known as "haze" or "aze" (figure 3.8) grows naturally throughout the Sahelian zone on the silt-clay soils of the plains, depressions or wadis temporarily watered by the rains and run-off water. Wild fonio grains are ovoid-shaped, but bigger and more globular than fonio grains. On average, they are 2.2 mm in length and 1.4 mm in width; 1,000 grains weigh approximately 2 g. The "hulls" are shiny and waxy (see colour photo album).

Figure 3.8. *Panicum laetum* Kunth (Busson, 1965).

1. Ligule – 2. Fragment of panicle – 3. Spikelet – 4. Lower glume – 5. Upper glume – 6. Lemma.

Wild fonio plains in the Gourma region of Mali

In Mali, this small annual plant, 30 to 60 cm in height, grows in abundance in Gourma, where it forms vast prairies, which are unfortunately being gradually worn down due to repeated droughts. Wild fonio is used as a livestock fodder plant, but its grains are also harvested to feed the nomadic populations, which consider it to be one of the best small wild cereals.

In 1991, Jens B. Aune gave a description of the harvest: "Fonio is harvested in two stages. The first stage of harvesting involves swinging a specially designed basket at the height of the inflorescences to collect the grains detached by this movement. Then, when the remaining grains are ripe and fall to the ground, the soil is swept after reaping the straw to harvest them. The grains mixed with the earth are then purified by winnowing. A considerable amount remains on the ground, which is subsequently used to sow for the following year. In Gourma, the harvest can begin in August and last until November. The grains are important for feeding the population of Gourma, and the surplus obtained is sold on local markets."

Wild fonio in the Brakna region of Mauritania

A description of the harvest (figures 3.9. and 3.10.) and use of wild fonio was made by the explorer René Caillé when he was staying with the Moors of Brakna, in the region of Lake Aleg (in the modern-day Sahel region of

Figure 3.9. Wild fonio harvest (T. Meudic).

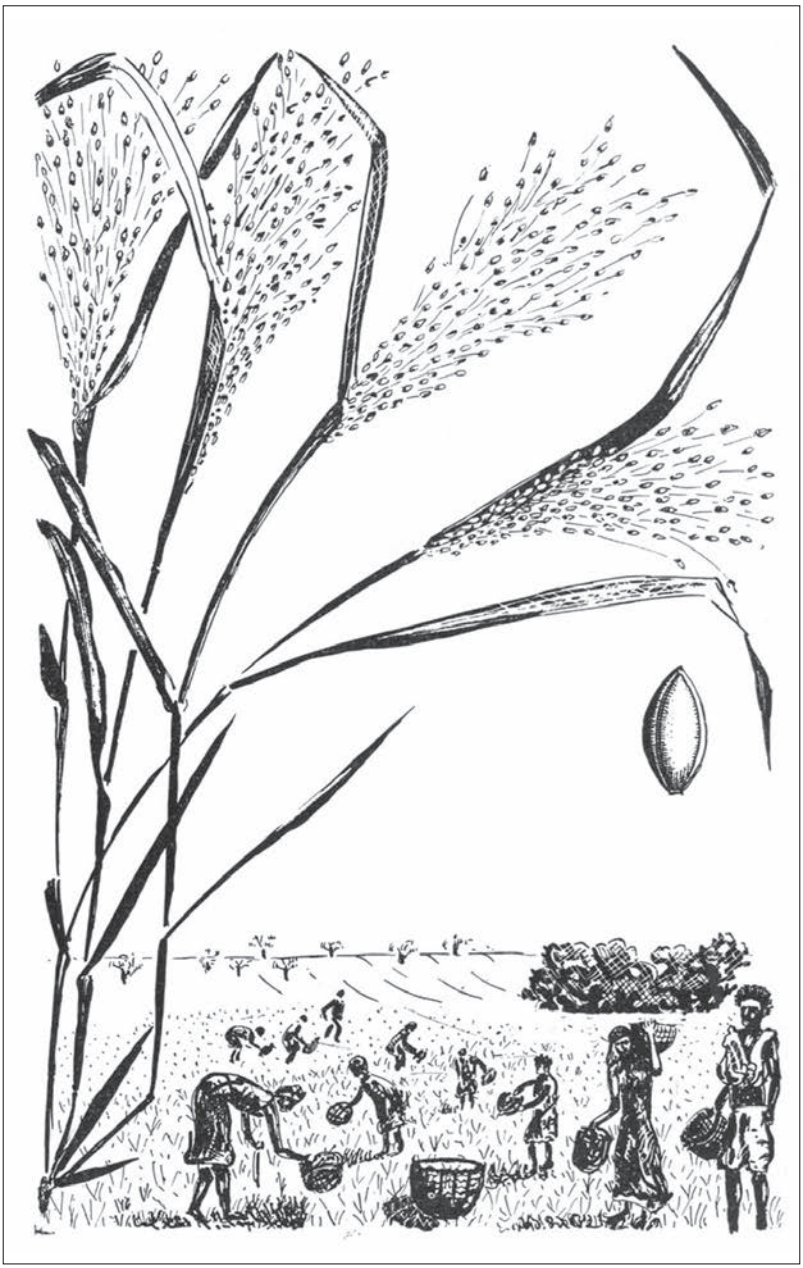


Figure 3.10. Scene of an aze harvest, showing the appearance of the plant (H. Jacques-Félix, 1963, © Publications scientifiques du MNHN, Paris).

Mauritania) in preparation for his voyage to Timbuktu. This was how he described his evening of 6 September 1824: "We dined very late, our meal consisting of *sanglé*, sprinkled with sweet milk. Having remarked that the grains making up this dish were whole, I asked the reason why; they told me that it was not millet, but haze, and that in this season the Marabouts used their slaves to gather it. This grain is very common and grows naturally, uncultivated. They showed me slaves engaged in this harvest: they were women, equipped with a small broom and two baskets; one of these, smaller than the other, is oval shaped, and with a handle on top. When the haze is common and has not yet been trampled by the livestock, they walk forward swinging this basket side to side, so as to rumple the edges of the spikes of the grass as they strike it; in this way the ripe grains yield and fall into the bottom. When they have gathered a certain amount, they pour it into the large basket, designed to hold the harvest. This method provides much cleaner grain than the second, though in less abundance, since not all the threshed grain drops into the basket, of course. When the grass has been trampled, or the first harvest has been carried out as I have just described, they cut the plant with a serrated knife that they carry for this purpose, and sweep the grain along the ground, and make small piles which they later pick up. And, since in this way there is more earth than grain, they separate it using the *layot*, which takes a long time." (Caillé, 1830).

René Caillé also specified that the daily harvest was just "five pounds", i.e. 2.5 kg.

Scale of production

According to the FAO (United Nations Organisation for Food and Agriculture), fonio production in 2013 amounted to 610,000 t for a harvest area of 580,000 ha. The average yield is around 1t/ha, but it can sometimes reach more in Guinea, a country which on its own accounts for more than 70% of production, whereas it can be less than 500 kg/ha in Niger and certain northern zones of Burkina Faso and Mali. The various production levels by country are recapped and expanded in table 3.4.

The evolution of production over the past 50 years (figure 3.11) shows a steep decrease in the quantities produced (from 180,000 to 130,000 t) during the 1960s and 1970s, followed by a steady recovery from the 1980s and a great increase since 2000. With yields remaining relatively constant throughout the period, this recovery in production is due to the expansion of cultivated surface areas and to the mechanization of post-harvest techniques since 2000.

Table 3.4. Fonio production by country in 2013.

Country	Production (t)	Cultivated surface area (ha)
Guinea	454,500	325,500
Nigeria	90,000	165,000
Mali	22,000	34,000
Burkina Faso	20,000	24,500
Côte d'Ivoire	16,500	15,000
Niger	4,500	10,500
Senegal	1,500	2,500
Benin	1,000	2,000
Total	610,000	580,000

Source: Faostat (rounded figures)

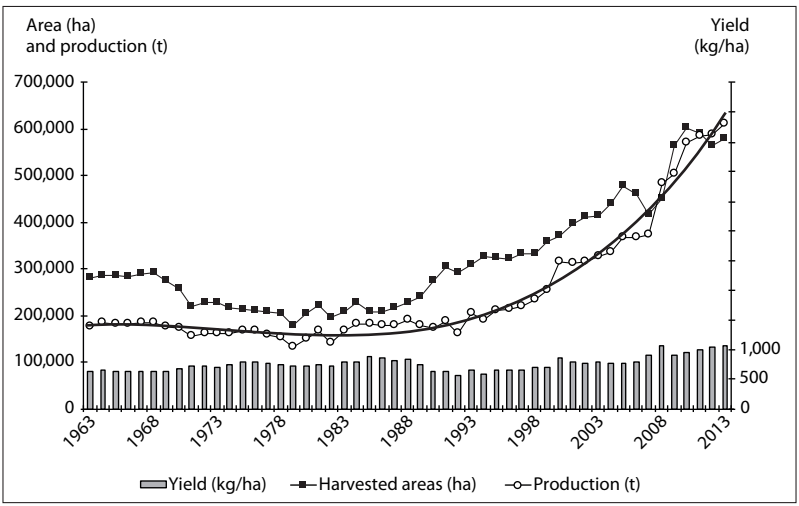


Figure 3.11. Evolution of fonio production according to Faostat.

Agricultural production practices

Fonio: a family agriculture product

Fonio is cultivated by numerous small producers practicing family agriculture on surface areas of 0.5 to 1.5 ha. In certain regions, fonio has been abandoned by men, to become a typically women's crop, with small surface areas of around 0.2 to 0.5 ha. In most of the production zones, fonio primarily plays the role of a lean season cereal during the most difficult months for obtaining

food resources. As already stated, by using short-cycle varieties or ecotypes, producers can meet the food needs of their family pending the harvest of other cereals like millet, sorghum, maize or rice. The latest fonios are kept on the smallholding for consumption during the year, particularly to mark ceremonies or festive periods, or to be sold, depending on the monetary needs of the households (Cruz, 2009). Through years of farming, farmers have managed to obtain numerous local cultivars well-suited to their environment, thereby contributing to the development of biodiversity (Niangado and Kebe, 2002).

Fonio cultivation is still today primarily manual, using simple tools *(a daba*, or traditional hoe) for soil preparation and a sickle for harvesting. Because it is not very technical, farmers have a good command of manual farming, but it is very often laborious and time consuming. On certain plains and for preparing large plots, farmers sometimes have to employ draught cultivation.

Fonio in crop rotation

Crop rotation is an ancestral method used to maintain or improve soil fertility and limit the proliferation of certain weeds. In many tropical zones, crop rotation takes several years, and when the soil is depleted, it is left fallow. Depending on the region and land availability, the length of the fallow period may vary from several years to more than ten or fifteen years. Currently, in certain zones, the fallow period is tending to decrease due to demographic pressure, whereas it may increase in areas of rural exodus. In the Pita region of Guinea, certain "elders" lament that the land is no longer cultivated, and are unanimous in recognising that fallow periods on land are increasing: the fields are cleared every ten to fifteen years at present, instead of seven to nine years as was the case in the past (André and Pestaña, 2002).

The farmer chooses a cropping plan according to his subsistence needs, the quality of the lands at his disposal and the monetary revenue that he can expect from certain crops.

In crop rotation, fonio is most often sown after a legume like peanut and cowpea, or even an oilseed like sesame, at the end of the crop rotation.

Examples of crop rotation have already been given above:
– Example 1: dry-land rice, dry-land rice, peanut, fonio, fallow (mountainous zone in Guinea).
– Example 2: dry-land rice, fonio, fonio, fallow (plain zone in Guinea).
– Example 3: millet, fonio, millet, fallow (Seno plain, Mali).

Fonio is rarely cultivated as the first crop, except sometimes in the hilly zone of Guinea, or naturally when grown as a monoculture on poor soils, on the plain, outside of the usually cropped plots.

In 1944, the geographer Jacques Richard-Molard gave some examples of crop successions on various types of soil in Middle Guinea: "In Tiri-Tara, near Mali, at an altitude of 1,400 m, good wooded dantari soils can produce fonio 7 years in a row: the grassy dantari soils just 3 years; wooded hansagnéré soils 3 or 4 years; cleared hansagnéré soils just one year; and fallow for 7 years, with no possibility of another crop. In Dandou, the best hansagnéré soils produce 5 to 7 years of fonio, which ultimately leads to pitiful yields. On the Labé plateau, where the population excess is causing abusive farming, dantari soils are sown with fonio 10 years in a row, and end up yielding just 150 kg/ha, barely twice the seed. In Timbi-Madina, cultivation barely gets past the 7th year. The average is between 3 and 6 years when the land is fit only for fonio – followed by a 7-year fallow period. A rich hansagnéré soil bears mountain rice for one year, and peanuts the following year; it is depleted by one or two fonio harvests, which is followed by a 7-year fallow period. A good hollandé soil can initially produce one, two or even three consecutive rice harvests, and then one or two fonio harvests. Poor hollandé soils are left for fonio, like dantari soils. The peanut can have the 1st year on a rich hansagnéré soil; after which fonio takes over to finish. Sometimes the peanut can take over from rice. A real sequence of crops is possible: one year of mountain rice; one of peanuts; one or two of fonio, and then at least a 7-year fallow period. It seems that the peanut (or rice) never succeeds fonio. Depending on the hansagnéré soil's value, we can have for example 3 years of peanut, and then one of fonio; or 2 of peanuts, then 2 of fonio; or one of peanuts and 3 of fonio. Fonio is always the end crop, like cassava in equatorial regions, since it is the best suited to nearly-depleted earth, which explains its overwhelming predominance on the high plateaux."

In most situations, farmers rotate their crops on a plot until weeds like striga (*Striga hermontica*) appear in great number, which is a sign of soil fatigue in cultivated plots. Farmers then sow a final year of fonio, since it is deemed the only crop that can still grow on a depleted soil. But in general, producers seek if possible to avoid cereals as a preceding crop, to minimise the presence of striga in fonio fields.

Fonio is sometimes cultivated in association with other plants like roselle *(Hibiscus sabdariffa* L.), as is the case in Upper Guinea, Mali and Burkina Faso. Some also recommend fonio as a preceding crop for cowpea, peanut or sesame, in order to limit the proliferation of *Macrophomina phaseolina,* a fungus responsible for charcoal rot on the roots of various crops in the Sahel zone, but which does not attack fonio. A recent study demonstrated that the development of charcoal rot can be significantly reduced in infested plots, and cowpea yields improved in farmers' fields by rotation of cowpea with fonio (Ndiaye *et al.,* 2008).

Pre-cultivation operations: cleaning up the plots and soil preparation

The main pre-cultivation operations, generally carried out by men and children, are cleaning up the plots, and then in particular using the *daba* (a local hoe as shown in photo 3.1), to manually work small surface areas (figure 3.12). For bigger fonio plots, ploughing is on the rise since it is faster and less tiring than manual techniques. Ploughing is most often carried out with draught animals (oxen, horses), and rarely with a tractor. Production units which do not have ploughing equipment or draught animals, as is often the case for farms managed by women, must call in service providers, which are often other producers (Vall *et al.,* 2007). This sometimes involves delays in preparing the fields, and in every case represents a major item of expenditure, which can be as much as 25% of total expenditure per hectare.

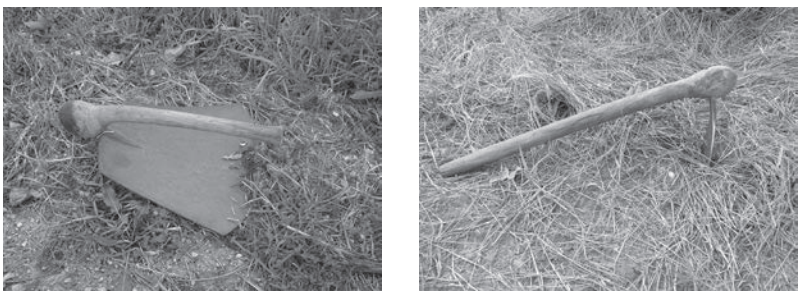


Photo 3.1. Various daba from Mali and Burkina Faso (© J.F. Cruz).

In Guinea, the pre-cultivation operations vary between cultivation zones. In hill and mountain zones, in the first year the land is cleared and burned before sowing; whereas on plain soil, ploughing is carried out, followed by harrowing, often using draught cultivation. Clearing is carried out from February to March in the mountains and from May to June in the hills. On the plain of Timbi Madina in Fouta-Djalon, draught cultivation is nearly entirely reserved for fonio cultivation (figure 3.13). Slash-and-burn practices generally involve temporary, so-called shifting crops (Mazoyer and Roudart, 1997), and are often blamed for the disappearance of certain fragile tropical forests. Hence fonio and mountain rice (or dry-land rice) have been accused of damaging Fouta-Djalon (Sudres, 1947), and have even been dubbed "leprosies eating away at the country" (Portères, 1955).

Sowing

Upon the first rains, or even earlier, the seeds are broadcast onto a mellowed surface soil (figure 3.14). The field is divided into several strips, and sowing

Figure 3.12. Hoeing the surface with the *daba* (Ceemat).

Figure 3.13. Ploughing (Ceemat).

is often carried out the same day, immediately after ploughing the fields, or put off until the next day if ploughing is finished at the end of the day (Daho *et al.,* 2007). The seeds used are raw fonio grains from the previous harvest, selected from the best grains from the best plots. They are kept separately according to their cycle duration (early, intermediate or late varieties) to prevent mixtures of varieties, which would lead to maturity differences on the same plot. For broadcast sowing, they are sometimes mixed with sand or ash to promote more homogeneous distribution of the seeds.

The sowing dates vary between agro-ecological zones and the appearance of the first rains, or depending on the varieties sown. They can be staggered from mid-May in the southern zones to early July in the semi-arid northern zones. In the mountainous wet zone of Guinea, certain fonios are sometimes sown nearly at the end of July. Depending on the region, producers sometimes decide to stagger sowing over time, so as to spread the harvesting. The sowing period is even considered by some as a variety classification criterion. The following distinctions are made:

– early sowing fonios, sown on dry lands before the first rain. If these fonios are also fast-growing, they are often considered to be lean season fonios (or "scarcity fonios");

– semi-early sowing fonios, sown upon the first rains;

– late sowing fonios, sown when the rainy season is well established, between late June and July.

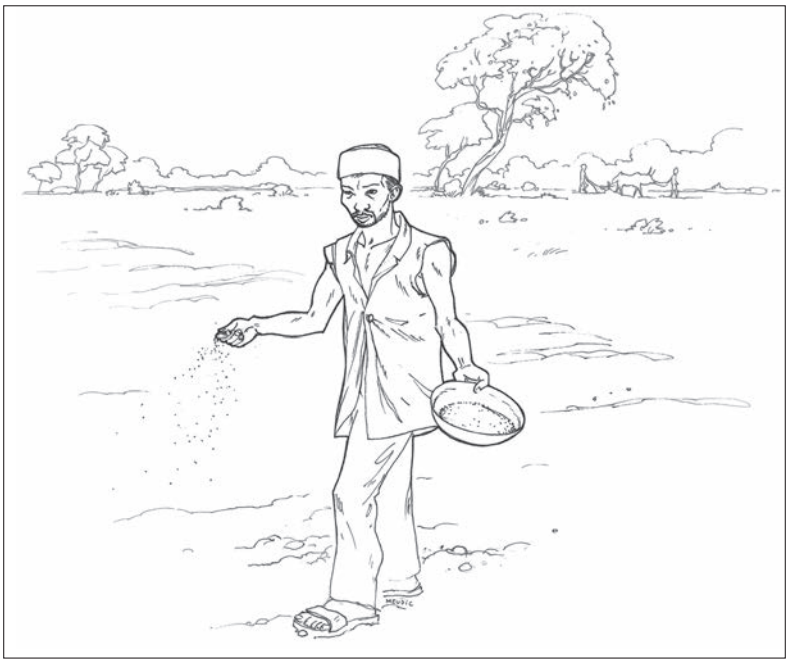


Figure 3.14. Broadcast sowing of fonio (T. Meudic).

In May 1827, the explorer René Caillé, who was staying in the village of Cambaya, close to the River Tinkisso and the current city of Dabola in Upper Guinea, provided a description of fonio cultivation: "The soil of these fine plains comprises a very hard grey sand, which is fertilised by the Tankisso when it overflows; the highest lands, which avoid flooding, are dedicated to cultivation of yam, cassava, maize, millet and *foigné*, another small grass species which is frequently cultivated. The *foigné* is sown in May, and it is harvested in July, when the rice is not yet four inches above the soil: it can be harvested twice a year. Without this grass, which grows with great rapidity, this country would often be exposed to the greatest food shortages, since these peoples have the custom of sowing just enough for their needs: indeed they often do not sow enough, and in this case they resort to *foigné*. […] However, they have only a single soil working implement, a pick, which is made locally; it is six inches long, and four wide; the handle, eighteen to twenty inches long, is sharply angled. They mix the earth to the depth of one foot for rice seeds, but for *foigné* seeds, they do not take such care; they simply cut the grass and broadcast the grains, before the earth is prepared; then they pull the grass back over to cover the grains: it is the women who are responsible for this fairly simple operation. They do

not even take the trouble, when the *foigné* has risen, to pull up the weeds hindering its growth. Rice is treated with more care: they attentively hoe it, to clear from it all weeds, without transplanting."

Fonio grains are very small. For this reason, they must only be buried at a very shallow depth. In 1955, Portères demonstrated that there was a limit to burial depth, with a lethal horizon at 6 cm and a theoretical optimum at 2 cm at a temperature of 30 °C, which seems to be the most favourable for germination. If the fields have been hand-worked, the grains are naturally sown on the surface, and then slightly buried by quickly hand harrowing or light hoeing with the *daba* or by sweeping over the sown soil with branches. Shallow burial is also necessary to prevent the grains from being consumed by birds or foraged by ants. The quantities of seeds used are 30 to 40 kg per hectare. On ploughed soils, the dose of seeds used may be greater, given that some grains buried too deep will not germinate correctly. Bigger seed doses (70 kg/ha or more) are also used by certain producers wishing to boost the success rate of their sowing and limit weed proliferation.

The idea of sowing fonio in-line has been regularly brought up by certain researchers. But it is nothing really new; in 1905, L. Renoux and P. Dumas, two crop specialists in West Africa working in the valleys of Senegal and Upper Niger, claim to have trialled it on agricultural stations, using 18 kg of seeds per hectare. They specified that: "Using a seed drill is advantageous when large surface areas are involved, when the seeds are expensive, which happens at certain times of the year. The seeds are distributed more uniformly, and the vegetation develops better. With broadcast sowing, there are always tufts that develop poorly, remain yellow and even perish. Finally, sowing in lines 15 to 20 cm apart makes weeding easy. It can even be executed with the mechanical cultivator." Yet mechanisation of sowing requires prior thought as to the various possible alternatives, considering

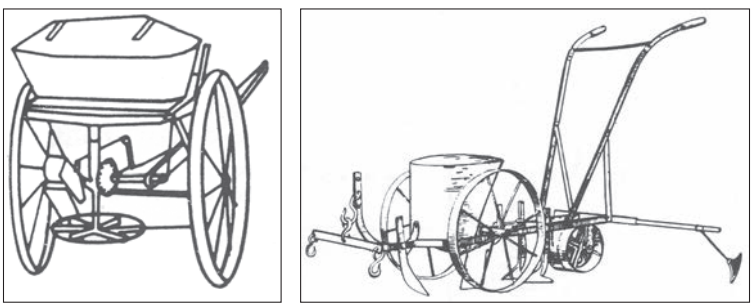


Figure 3.15. Broadcast seed drill and SuperÉco single-row seed drill for draught cultivation (Ceemat).

their advantages and shortcomings: mechanised broadcast sowing, bunch sowing with a single-row seed drill (figure 3.15), sowing in continuous lines, multiple-row sowing with a market gardening seed drill, etc.

Germination and crop maintenance

Upon the first rains, when the seeds encounter favourable temperature and moisture conditions, germination takes place quickly, within a few days. However, the rains must not be too violent, as this could shift the seeds, or bury them too deeply. By sowing on dry soil, tornadoes over the dusty soil at the beginning of the rainy season can cause the greatest damage and force the producer to re-sow his field. For germination and field emergence, a temperature of 30 °C seems to be optimal. In 1905, L. Renoux and P. Dumas provided the first description of fonio germination: "In three days the cotyledon appears; the field is a dark green colour. Highly drought-resistant, the young plant does not perish, although the next rain might not come for one or two weeks. The leaves curl up and dry out, but as soon as the moisture reappears, the plant starts growing again." This ability of young fonio plants to adapt to poor soils and the random nature of the rains at the beginning of the rainy season makes fonio one of the most resistant plants to climate change and drought.

In 1955, R. Portères also described its germination and plantlet development (figure 3.16):

1. "Fonio germinates very rapidly, and the germinating capacity is easily retained for 2 years. The radicle emerges first, then comes the coleoptile, but the difference in growth rates is immediately such that one often gets the impression that the coleoptile emerged first. The radicle develops absorbent hairs fairly late, and does not exhibit a club shape at its end, as is generally observed in Paniceae."

2. "The pre-leaf which develops pierces the end of the coleoptile before the root undergoes ramification." "The green pre-leaf has purple borders in many breeds, is only exceptionally bronze, and is always hairy in fonio (always hairless in Iburu); initially rolled into cornet and hooded by the coleoptile, it gradually unfurls to subsequently extend lengthwise, as in all Paniceae[…]."

3. The first crown root (mesocotyl root) generally arises upon nutation of the first true leaf, when the primary root ramifies. […] Unlike what happens in *Eleusine coracana*, for example, the tigella does not develop quicker than the root system. Hence an equilibrium is established between the organs, which helps initiate fonio vegetation in poor and very light soils."

4. "All the leaves following the pre-leaf are tiered in the distichous position; the pre-leaf is angled 180° from the first leaf […]."

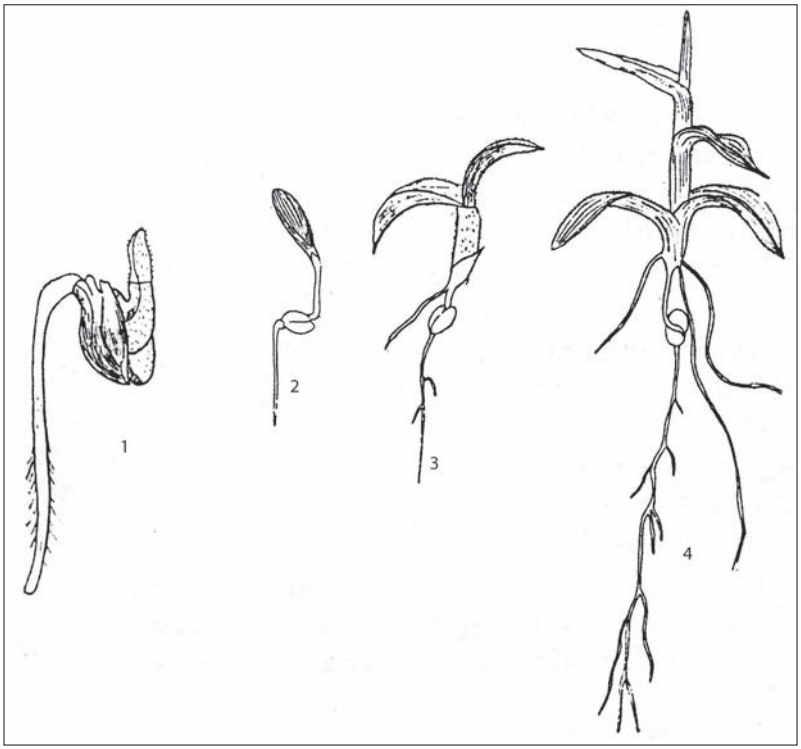


Figure 3.16. Germination and development of fonio plantlet (according to Portères, 1955).

At the beginning of germination, the young shoot draws much of what it needs from the seed, and then the plant becomes completely self-reliant. Like many Gramineae of tropical and arid origin, fonio employs so-called "C4" photosynthesis, which enables a high dry matter production rate in relation to quantities of water absorbed. Photosynthesis is optimum even when the plants open their stomata only marginally, which reduces water losses via transpiration.

Although fonio is very hardy, and requires little maintenance during cultivation, it is good to eliminate the weeds to obtain a decent yield (Vall *et al.,* 2008a). A first weeding is often carried out after four to seven weeks of vegetation. If carried out early, i.e. one to two weeks after sowing, it may significantly benefit yields at harvest, insofar as it limits competition between fonio plants and weeds. This weeding, which consists in manually uprooting the weeds, is a delicate operation which requires particular know-how to correctly distinguish the young fonio shoots from the weeds. This painstaking

operation is generally carried out by the women, children or the elderly, or less commonly by external labour. Weeding calls for a relatively large quantity of labour. The labour time for weeding varies from 6 man-days per hectare in semi-arid zones to 16 man-days per hectare in subhumid zones where weed growth is usually greater (Daho *et al.,* 2007). To separate fonio from other Gramineae, it is often necessary to wait until flowering, at which point a second weeding is essential. If, due to a lack of time or man power, weeding is not carried out, the yields are affected and the seeds collected during harvesting could be mixed up with the seeds of various weeds.

It has already been said that striga *(Striga hermonthica)* is one of the main enemies of fonio growing on depleted soils. This plant parasites on many other Gramineae such as dry-land rice, maize, millet and sorghum (Chantereau *et al.,* 2013).

Weeding operations are often the only fonio cultivation maintenance operations; which leads many producers to say that fonio is an "easy" crop.

Striga

In their work on sorghum, Chantereau and Nicou (1991) provide a description of this parasitic plant:

"The genus Striga covers around thirty species, 23 of which are present in Africa, where they occupy the land in a great variety of ways […].

The duration of the biological cycle of striga from germination to seed production is between 90 and 120 days. There are four distinct phenological stages: germination, fixation on the host, penetration and flowering-fruit bearing. The first three take place beneath the soil surface, and the last is above ground.

The very small striga seeds are produced in great quantity (40,000 seed per plant), and can last for fifteen to twenty years. They are disseminated in the environment by water and wind. Their dormant period is between two and six months, which corresponds to the dry season of countries with a semi-arid tropical climate. At the beginning of the cultivation season, the grains soak up water (preconditioning phase), so they need a germination stimulant produced by the host plant [...]. This stimulation causes the seed to emit a radicle which grows toward the root by chemotropism. A swelling appears on the radicle (creation of the haustorium), the parasite's organ of penetration into the host. On the striga seed, a tuber develops, from which roots appear […].

In the Sahelian zones where the sowing period is around June, striga emerges in August. Flowering and fruit bearing begin in mid-September, and can continue until late October.

In terms of curative control, uprooting of the strigas before flowering and burning are efficient methods."

During the vegetation process, fonio fields will adopt various colours: dark green, and then soft green. Finally, when the grains reach maturity, the colours shift to yellow, red or brown, depending on the varieties sown and the pigmentation of the stems or spikes. Renoux and Dumas (1905) spoke of a Bérélé oulé variety with very red glumes, which on maturing gives the field a rusty appearance.

In cultivation, fonio suffers little depredation, although some farmers sometimes complain of attack by certain insects (cantharid species), birds or mammals (wart hogs). Thus fonio may undergo a short monitoring period against birds for the first few days after sowing, or just before harvesting.

Producers do not use any chemical products or input. In Middle Guinea, certain farmers who plant fonio on the same plots every year sometimes apply NPK fertiliser, but this is relatively rare. If need be, recent research has shown that it is doubtless preferable to apply a moderate fertiliser input via a preceding crop such as legumes, or by adding manure (Gigou *et al.,* 2009). Thus compared to many other products, fonio, which in most regions is treated with neither fertiliser nor pesticides, has the advantage of being an "organic" crop, which can be promoted as such.

Flowering and reproduction

A plant, and more specifically a variety, is characterised by the duration of its growth cycle which, divided into vegetation periods, illustrates the various stages of development. Hence several phases can be distinguished: installation, panicle initiation, flowering and maturation. In the Sudano-Sahelian zone, many so-called "traditional" cereal varieties such as millet or sorghum express photosensitivity to the length of the day, and are referred to as "photoperiodic". Depending on the variety type, the flowering date is relatively constant, regardless of the sowing-emergence date. "The plants wait to flower together." Research conducted in Mali by CIRAD and the IER (Institute for Rural Economy) demonstrated that fonio was also a photoperiodic cereal that can regulate the duration of its vegetation phases in line with the earliness of the sowing date. Like most tropical plants, fonio flowers mainly in the "short days."

The inflorescence of fonio was described by Portères (1955). It most often comprises two or three racemes. The racemes bear highly interlinked spikelets grouped in twos, threes or fours on pedicels. The spikelet with glumes has a sterile lower flower and a fertile upper flower with lemma and palea. The upper flower has three stamens with white or purple filaments and anthers which are yellow or yellow with purple pigmentation. The superior ovary has two white to pink to dark purple feathery stigmas, depending on the variety.

Many authors have long asserted that fonio was allogamous, and that it was thanks to this cross-pollination (or interfertilisation) that fonio retained a relatively high genetic diversity (Vodouhè and Achigan Dako, 2006). Very recently, a team of researchers from Benin and Germany showed that fonio reproduced mainly by apomixis with little autogamy (Adoukonou-Sagbadja *et al.,* 2007). Apomixis is a genetic particularity of certain wild plants, such as dandelion, where seeds are produced with no real fertilisation (i.e. without meiosis or chromosome separation, or fertilisation or chromosome mixing). The resulting seeds are clones of the mother plant. These initial results, obtained in 2010, need to be confirmed.

Genetics of fonio

The ploidy of fonio has long remained obscure. In the 20th Century, *Digitaria exilis* was believed to have: 2n = 54 chromosomes (Purseglove, 1985; NRC, 1996).

Adopting a base number of chromosomes of x = 9 as for other Paniceae, several authors concluded that fonio was hexaploid, with 2n = 6x = 54 (Portères, 1955; Haq and Dania Ogbe, 1995). Yet some suggested that fonio could be diploid (2n = 2x = 18) or tetraploid (2n = 4x = 36) (Baudet, 1981).

Recent research conducted in 2006 on 94 West African varieties concluded that fonio was tetraploid, although diploidy or hexaploidy could exist, though with a relatively low occurrence (Adoukonou-Sagbadja *et al.,* 2007).

4. Harvest and post-harvest

Manual harvesting

The harvest is carried out as soon as the grains reach maturity, from the months of July and August for certain early varieties. The harvest of the early fonios is a time eagerly anticipated by local populations, whose food reserves are depleted at this period of the rainy season.

In 1905, L. Renoux and P. Dumas described this period: "The harvest time of the first fonios is the most active of the rainy season. Rains are torrential and almost daily. Water courses gradually encroach on the surrounding land. The native, whose granaries are depleted, goes every day to his *lougan* to see if he can reap […]. Finally, it is ripe. Between storms, when a feeble sun has dried the field a little to allow the reapers access, the owner, with the help of the whole family, begins the harvest. He cuts with a sickle; and then assembles the stems in small sheaves of two to three kilos, which he leaves on the soil for a few hours, if time permits. Finally, he houses them in a barn or in a homestead. Fonio must be handled with care. Most of all when it is dry, the grains drop off extremely readily. The reaper must always work with a certain moisture content."

To this day, reaping has remained an exclusively manual task. It is carried out using a sickle (figure 4.1) by the men from one family, or by mutual assistance groups which go round the fields of the various group members one by one. Women who run smallholdings must often call in temporary personnel. The reaping operation is highly demanding in terms of labour,

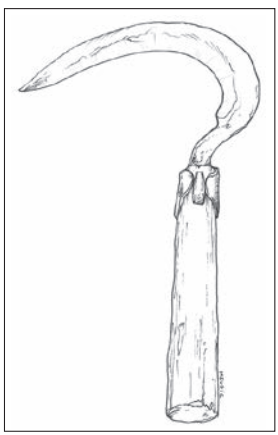


Figure 4.1.
Sickle harvesting (T. Meudic).

and generally requires 20 to 30 man-days per hectare. The reapers are divided between working strips on each plot, and thus progress together, in the same direction and slightly staggered to prevent any unreaped spots or risks of accident (figure 4.2). Reaping requires real know-how, since mature fonio plants are generally highly lodged, and most of the stems are lying on the soil. The reaper, moving in the direction of lodging, must lift the stems before cutting them. The cut stems are then assembled by the women and children in small piles of 1 to 3 kg, which are gathered into sheaves, and then transported in baskets and placed under shelter near the homesteads to protect them from the rains. During this rainy season when the atmosphere is particularly humid, the sheaves must be properly aerated to prevent any risk of overheating or mould development.

In 1940, D. Paulme described the fonio harvest of the Dogon people in Mali. It was the only time of year in which the men and women, to boost their efforts and alleviate their fatigue, could permit themselves teasing and cheeky chants, outside of the usual rules of politeness and good manners.

Figure 4.2. Manually harvesting fonio (T. Meudic).

Reaping height

Depending on the zone, reaping height can vary depending on whether the fonio straw is used. If harvesters wish to reduce the transport costs and threshing efforts, then the fonio stems are cut at the upper third. This leaves the bulk of the straw on the field, which can then be grazed or reincorporated into the soil in the next ploughing. Conversely, reaping is carried out as close as possible to soil level if the harvesters wish to use the straw as fodder or as material, or to obtain potash after burning, as is the case for some producers.

Surveys conducted in Mali and Burkina Faso show that the opinions of the farmers diverge regarding the ability of fonio to regenerate soil fertility. Certain very devout producers attribute the ability of fonio to fertilise the soils to divine powers, while others consider that the wind, rainwater, trampling by humans and animals, and the presence of termites on the fonio stubble after harvesting improve the fertility of a fonio field (Daho *et al.,* 2007).

"The fonio harvest, unlike for millet, is a communal activity: if one of its members is to reap, the whole district, or *togu*, comes to help. They respect seniority among the various owners – the fields of the elder are reaped before those of his juniors. The man on whose field they are working feeds the reapers. They come early, but the sun is already high when the girls bring the meal that they prepare in the village: millet gruel and fish cooked in shea butter; all sprinkled with generous draughts of the juice obtained from steeping *pegu* fruits. The work resumes after a short nap: the men cut the stems with their sickles, while the women, following in their footsteps, gather and stack them. In spite of the efforts they expend, the natives all seem to consider the fonio harvest as one of the most appealing times of the year; they await it with a most understandable impatience, and talk about it long after… There are even some plainly obscene chants, known as "*pô ga ni"*, literally "songs for the fonio harvest", which can only be sung on this occasion."

In the semi-arid and subhumid zones, the main fonio harvest period occurs at the end of the rainy season between mid-September and mid-October. Conversely, in wetter zones of Fouta-Djalon, the late fonio harvest can last until late November even. At these times of year, the rains are increasingly rare, as the dry season gradually returns. Harvested sheaves require less care, and can be left in the field.

The efficiency of reaping could be improved by using scythes or motor mowers. In 1905, L. Renoux and P. Dumas, who had contemplated using a scythe for fonio harvesting, specified: "As we have said, the sickle is the only practical tool to use with varieties which lodge completely on the soil. But

the scythe, which we have employed in agricultural stations, is far better for fonios which remain somewhat erect, provided that reaping is carried out in the dew so as not to lose too much grain."

Later, in 1929, on a mission conducted in Guinea, Professor Émile Perrot remarked that some rice reaper trials had been successfully conducted at Timbi-Touni in Fouta-Djalon, and that the reapers had also worked with fonio. His report presented in particular an illustration of mechanical fonio reaping with an animal-draught cutting blade comparable to that set out in figure 4.3.

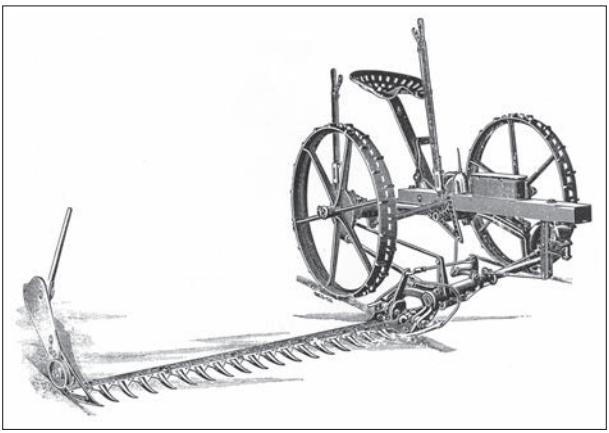
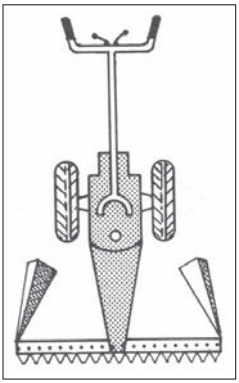


Figure 4.3. Animal draught reaper (Osborne).

Yet this reaping technique was apparently not developed. The work was doubtless exhausting for the animals, and the lodging of fonio does not facilitate mechanical reaping. Today, many specialists believe that in terms of harvesting, use of draught animals is limited to picking peanuts, and does not lend itself to reaping cereals. The animal-draught traction reaper, with an intermediate cutting bar (1.07 to 1.27 m wide) and a wheel-driven mechanism, designed for harvesting fodder in temperate zones, cannot be used for cutting natural grasses or legumes in tropical zones. The phytomass is very often too great (Lhoste *et al.,* 2010). In the 1980s, Jean Nolle, a French farmer and inventor, had proposed attaching to his famous "tropicultor" tool carrier a cutting bar driven directly by a small 4 hp auxiliary engine, to alleviate the hitching and facilitate cutting (Nolle, 1986). This fodder mower, which can also harvest rice and other cereals, has reportedly been tested convincingly in France, Africa, Asia and Central America, but without seeing any real development.



Today, on well-worked plain land, with the stumps properly cleared, small motor mowers (figure 4.4) could be tested, such as those used in Europe for mowing lawns or mountain prairies. But the main difficulty will remain the lodging of mature fonio. Equipment servicing (sharpening the blades, adjusting the guides, etc.) and maintenance are essential for correct operation, and represent major constraints for users.

Figure 4.4. Motor mower with frontal bar (Cneema,1976).

Storing and drying the sheaves

The sheaves harvested at the end of the rainy season are generally stored in cylindrical stacks near the homesteads, or directly in the field. These stacks are erected on wooden log platforms raised around fifty centimetres above the soil, to promote aeration and facilitate natural drying in the sun (figure 4.5). The stacks are made by stacking the sheaves in concentric circles to a height of 1.5 to 2 m, with the spikes facing inward to prevent bird attacks. A stack can contain up to one thousand sheaves, equal to more than 300 kg of grains.

In Fouta-Djalon, after setting nine sheaves, it is customary to throw the tenth loose inside the stack. This practice is known as "the field tithe", and the grains obtained after threshing this tenth sheaf were traditionally offered to the needy.

L. Renoux and P. Dumas described the method of drying and storing fonio sheaves harvested in the wet season: "The sheaves, brought under shelter, are arranged in cylindrical stacks, with the spikes in the centre. These stacks must be small, from 1 to 1.50 m high at most, to prevent overheating. When the harvest is abundant, it can be stacked in more or less long rectangles, but always at a low height. Nonetheless, the temperature soon rises in the stacks. It must be closely monitored to prevent it from becoming too intense and making the grain sterile. If necessary it is brought down by demolishing the stacks. Mould must also be guarded against. The first sheaves are lifted to see whether the inside has been invaded by white, and to smell the degree of odour and its nature. Mouldy sheaves must be taken into the sun, and the most afflicted ones untied. Grains impregnated with mouldy odour have no market value."

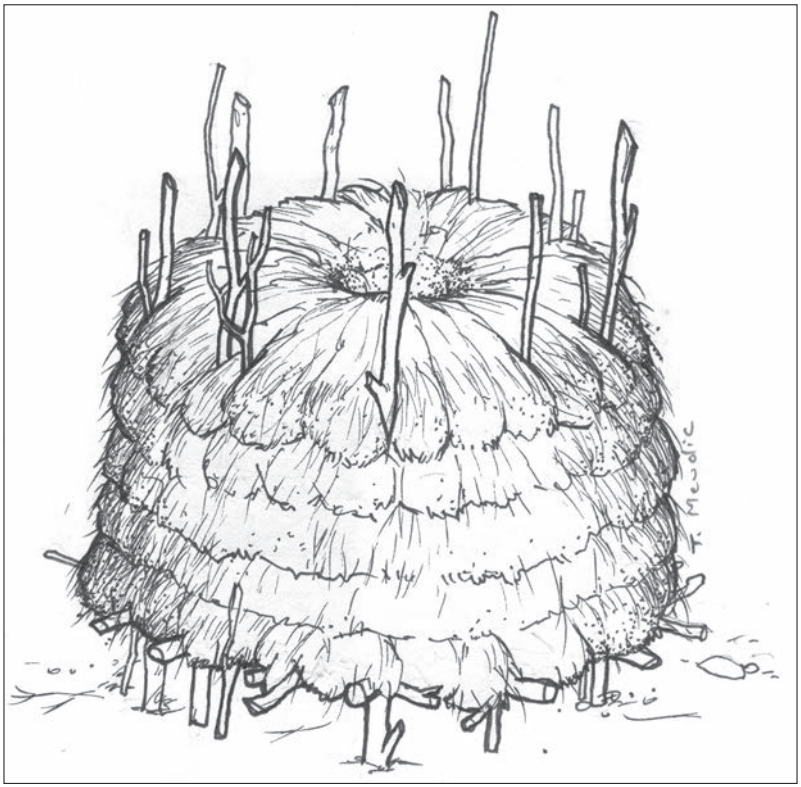


Figure 4.5. Fonio sheaf stack (T. Meudic).

They also talked about the storage of late fonio sheaves harvested at the end of the rainy season: "The harvest of the last fonios, carried out at the end of the rainy season, with showers becoming rare, no longer requires such precautions. It is left in the field, arranged as follows: two big stakes are driven vertically into the earth, protruding by 3 metres. They are used as a support for cross-bars staggered 50 centimetres from each other. The fonio sheaves, attached at their base in pairs, are straddled onto these cross-bars, superimposed in as many rows as the intervals permit. The spikes hang outside. By covering the highest row, the whole is sheltered. This arrangement is highly advantageous in preventing any alteration. The crushing is no longer a matter of urgency."

This description of drying and of the field storage of fonio sheaves on horizontal beams dates from 1905. It is quite comparable to that made by the explorer René Caillé, in July 1827, on his way into the Ouassoulo (or

Ouassoulou) region of Upper Guinea bordering modern-day Mali and Côte d'Ivoire. This is his account of the work of the local farmers: "[…] As I crossed a fine, well cultivated plain, I saw many workers spread across the landscape, who were digging the earth and mixing it as expertly as our vine growers in France; […] they are real labourers who work to obtain a fine and abundant harvest. They are well rewarded, since their rice, and everything they cultivate, grows faster and produces more than in Kankan. I have seen them harvest *foigné*: they use a sickle to cut it, and in many places are accustomed to leaving it in the field, exposed to the rain; they drive into the earth stakes in two rows, and artfully place their grasses between them; thus arranged, they resemble a palisade. The top is covered with straw, which prevents the rain from entering. As they need *foigné*, they come and take it, and no-one ever takes the liberty of stealing from this kind of store."

This traditional drying technique, which resembles the "palisade" or "rack" dryers used in the past in Europe for drying hay in the field, was illustrated (figure 4.6) by H. Jacques-Félix (1963).

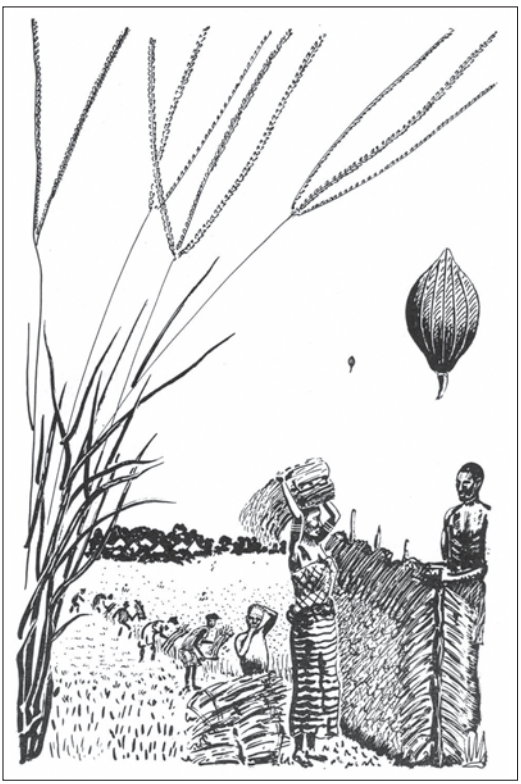


Figure 4.6. Fonio field, reapers and drying of sheaves on a "rack" (H. Jacques-Félix, 1963, © Publications scientifiques du MNHN, Paris).

Threshing and winnowing

After a storage period under shelter near the homesteads or in the field, the fonio sheaves have partially dried. Threshing, which consists in separating the grains from the stems, can then be carried out. For early fonios, which are used as lean season food for farmers, eager to consume the fruit of their first harvest, threshing begins very soon after harvesting. But generally the storage and drying time of the sheaves before threshing is one to two weeks or more. In the semi-arid zones of Burkina Faso or Mali, where the big harvest takes place toward the end of September, the fonio transported close to the homesteads is threshed in the first ten days of October. In sub-humid zones, the fonio stacks left in the fields are generally threshed from mid-October, whereas in Middle Guinea, threshing of late fonios harvested in November is often delayed until the end of December, or even later.

The threshing areas, whether in the field or near the homesteads, are always prepared with care to minimise contamination of the grains by various soil impurities (grit, pebbles). These areas are generally made from packed dirt and coated with cattle manure mixed with clay, and are only very rarely covered in concrete. Near the homesteads, they are sometimes covered with mats or plastic sheets.

Manual threshing is commonly carried out using rigid rods, or sometimes more flexible sticks. It is generally carried out by village mutual assistance groups which work in rotation for the owners of the fields, who are responsible for feeding them on the whole days that the operation can last. This laborious activity is carried out by men or young people, who can use this occasion to demonstrate their stamina. In certain regions, threshing still has a festive character, where chants accompanied by drums and balafons mark the rhythm of the toil (figure 4.7). In the Orodara region of south-west Burkina Faso, big threshing operations can involve more than fifty people. Manual threshing remains productive, and requires approximately 15 to 20 man-days per hectare. After reaping, it is the agricultural practice which requires the most labour (Vall *et al.,* 2007).

In 1940, Denise Paulme described fonio threshing in Dogon country: "Four or five days after reaping, in order of age, all the young people of the district, girls and boys who have not yet had children, come at night to thresh the fonio that the women have arranged in piles in the field. The work is obligatory, and no-one can get out of it without paying the eldest of the workers a fine of five hundred cauris, enough to buy millet beer at the next market. While his comrades use bent sticks as a scourge to thresh the stems on an area of hard ground, a young man plays the horn. The young girls are responsible

Figure 4.7. Traditional rod threshing of fonio in Burkina Faso (T. Meudic).

for winnowing, and throw the mixture of hull and grain into the wind. The threshed fonio is then placed into goatskin sacks, which will be handed over to the owner of the field. He thanks the workers; during the dry season, he will offer millet to those who have threshed his grain, to the tune of one measure per sack of grain threshed. The girls will convert the millet into beer, which the young people will share: this is *po bunu konyo*, beer for threshed fonio."

In other zones, to limit expenditure, threshing is carried out by family members. Monitoring a "rod" threshing operation, in the village of Darsalam near Labé in Guinea, provided the opportunity to verify some data on this type of family threshing. An area of 20 to 25 m^2, covered with plastic sheets, is used by a group of five people comprising four women and one man. Usually a dozen sheaves per person are untied, with sheaves weighing on average 600 g. Thus a mound of around sixty sheaves is built up in the centre of the threshing area. Then, equipped with a flexible one-metre rod in each hand, the five operators move around the pile, in rhythm, striking the sheaves, which they periodically turn over with their feet. Measurements taken during the operation showed that the grains represented 40% of the sheaf weight (the remaining 60% being straw), and that the throughput of manual threshing was 7 to 10 kg of grain per hour and per person (this throughput can be as much as 15 kg/h if the threshing is carried out by young men). Yet this threshing is really exhausting work, requiring frequent rest breaks during the process.

Traditional threshing can also be carried out by trampling or crushing by foot. Supporting themselves on a horizontal bar or on rods, women or

children rub the sheaves one by one between their feet to separate the grains from the stem. Here too, the rhythm of the work can be kept by chanting, with the "threshers" dancing on the fonio (see colour photo album).

Once threshed, the large straws are collected manually, and most often used for livestock feed. The mixture of grains and small straws remaining in the threshing area is then placed into coarse-woven baskets, which act as sieves and can retain the coarse impurities, while allowing the good grain and fine impurities to drop into a collection basin. Finally, using winnowing baskets or sieves, the women or elderly finish by separating the fine impurities from the good grain.

To this day, this threshing practice is, in all ways, identical to that described in 1905 by L. Renoux and P. Dumas: "Fonio can be crushed two days after harvesting. The grain has finished receiving from the stem everything that the stem can give it; its maturity is complete. There must be no great delay for the first fonios. If they wait more than eight days to grind it, the grain is invaded by mycelium, whatever the precautions they have taken. Crushing is carried out on an area covered with mats or ox hides. In the standing position, with his hands supported on a bar, the worker rubs the sheaves between his feet one by one, without untying them. When the seeds are more or less detached, he unties the sheaf, tramples it again, shakes it and then moves on to another sheaf. This work can be done by the children. In schools, the children are obliged to crush the fonio of the *karamoko* (schoolmaster). Because of the glumes remaining stuck to it, fonio grain retains moisture. It is spread out in the sun in thin layers to dry thoroughly. The native finishes cleaning his product by pressing it with to-and-fro movements onto a hide or in a winnowing basket. Contaminants gather on the surface. In short, this is a real winnowing process. We note that fonio crushing using the native method is a long operation. We have seen it practiced very rapidly using a small thresher, equipped with shakers, which at the same time eliminated the need for winnowing. When the grain is thoroughly dry, which can be recognised by the ease with which it slides between the fingers, it is enclosed in rush sacks or in bamboo baskets."

Because of its laboriousness, threshing is the operation for which the men would like access to specialised services. In some very rare cases, the sheaves are threshed by trampling using a tractor. Yet this relatively costly technique (10,000 FCFA/ha, i.e. €15.2/ha) may cause losses by burying grains in the soil. Although back in 1905 L. Renoux and P. Dumas referred to the mechanical threshing of fonio, it is only very recently that research has developed fonio threshers which can be built locally, and which might see wider distribution (see chapter 6).

Added-value uses of fonio straw

Fonio straw is often used as cattle fodder, but also for goats, sheep, etc., as is the case in particular in the most arid zones where animal food sources are rare. In many regions, fonio straw is also used for making mattresses. Some producers burn this straw to obtain "potash".

Fonio straw can also be mixed with earth for use as reinforcement in manufacturing banco, a clayey earth mixed with water, which undergoes long crushing by foot, and is used for village construction.

Whatever the regions, a large proportion of fonio straw is often abandoned, though proper added-value uses are possible as organic fertiliser or fodder, in particular by adding urea. Organic fertiliser production from fonio straw processed in composting pits was tested as part of the recent project on fonio (Vall *et al.,* 2008b).

Drying the grains

Grain drying is necessary to prevent risks of alteration by mould during storage. To ensure good preservation, their water activity, or $a_{w,}$ must generally be less than 0.6; below this threshold, micro-organisms cannot develop and enzyme activity is prevented (Cruz *et al.,* 1988). Hence the fonio grains must be dried to a storage moisture content of 11% or less, like the sorption isotherm of fonio shown in figure 4.8. It is interesting to note that this value is less than the value usually recommended for other cereals, under the same temperature conditions, and which is often 13%.

Sun drying is commonly carried out by spreading the grains on drying areas for several days. The threshing areas or terraces of homesteads are often used to this end. Depending on the zone, mats, plastic sheets or hides may also be used.

In the rainy season, natural drying cannot always correctly dry the grain from the first harvests. In certain regions of Guinea, the tradition consists in "grilling" them in a metal container placed on a hearth or heated metal plate, before hulling them for consumption. This grilling finishes the drying process by contact, which facilitates hulling.

Grain storage

Like rice, it is in the form of "paddy" or "dressed grain" that fonio is usually preserved. Like other cereals, it is generally stored in bulk (photo 4.1.) in traditional earth or "banco" granaries (photo 4.2.). The density of raw fonio is 650 to 660 g/l. In certain cases, it is packed into sacks, in particular when

Fonio sorption isotherm

The air-fonio equilibrium curve was produced at the CIRAD Montpellier laboratory. The wet base equilibrium water content (H% wb) was measured at 30°C, enabling the characteristic isotherm of raw fonio at this temperature to be tracked. The X-axis value is a_w (water activity). Data from the experiment were smoothed using the GAB (Guggenheim, Anderson, Boer) model.

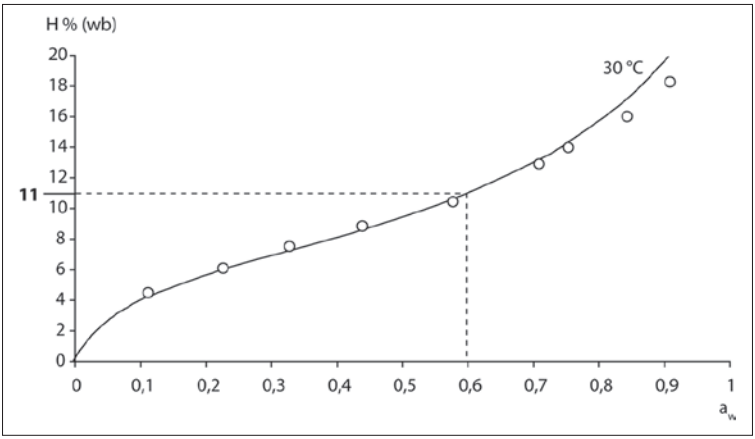


Figure 4.8. Sorption isotherm of raw fonio at 30°C (Cruz *et al.,* 2009).

intended for sale in the form of raw fonio or hulled fonio. Certain producers are starting to use metal drums or plastic canisters to preserve the hulled grains.

Doubtless because of its very small size, fonio generally suffers few pest attacks during storage. If it is correctly dried to a moisture content of less than 10 or 11%, it can be kept for long months, or even years, even in traditional storage structures.

As consumption needs arise, the fonio is taken from the granaries to be hulled and whitened before cooking. We shall now leave the domain of post-harvesting and enter that of grain processing.

Photo 4.1. Fonio stored in bulk in a traditional granary (© É. Vall).

Photo 4.2. Traditional banco granaries for cereal storage (© J.F. Cruz).

5. Processing and grain quality

Like rice, fonio is only consumed when hulled, and, most often, whitened. Yet in July 1827, when René Caillé described Ouassoulo in Upper Guinea, he hinted that the inhabitants consumed fonio raw:

"The country is watered by the River Sarano, and several large runoffs which fertilise the land; it produces in abundance everything that a sober man needs to live. The inhabitants are peaceful, humane, and highly hospitable […]. Their food is very simple: as in Kankan, they eat rice, *tau* and unground *foigné*; they add to this dish a sauce made with herb leaves or grilled *pistaches*; rarely do they employ salt, which is a luxury item, and they eat meat only on days of celebration; to their sauces, as well as gumbo, they add dried and ground baobab leaf." (Caillé, 1830).

As the explorer was a fairly attentive observer, it can be assumed that the fonio which he described was not completely whitened, but it may actually have been hulled.

Physical structure and composition of fonio grain

Fonio grain structure

Raw fonio

As already specified, fonio is a husked cereal, whose grains, after threshing, are surrounded by "hulls" (figure 5.1). This "paddy fonio" is not edible as-is because of the presence of these cellulose-rich hulls (glumes, lemma and palea). Raw fonio grains have an ovoid shape, slightly flattened on the back. They are very small in size (approximately 1.8 mm in length, and 0.9 mm in width).

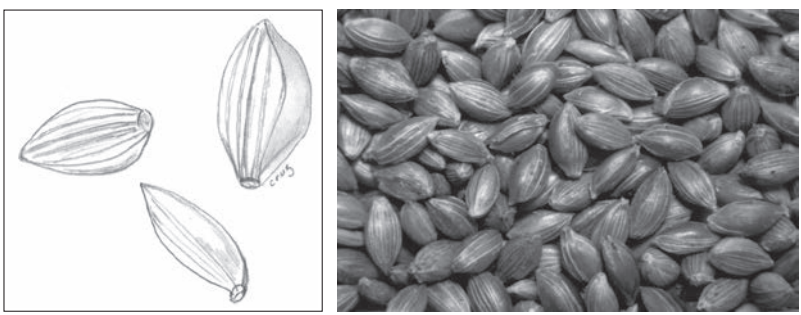


Figure 5.1. Raw fonio grains (© J.F. Cruz).

Hulled or "whole" fonio

Eliminating the hulls yields a naked grain called a caryopsis. Anatomically, these hulled fonio grains are similar to wheat, maize or millet grains, which are naked grain cereals. The hulled fonio grain, also known as "whole fonio", has a shiny pericarp, white to yellow to violet in colour, depending on the variety (see colour photo album). It measures just 1.4 to 1.5 mm long, 0.8 to 0.9 mm wide and 0.6 mm thick. On one side, the hilum can be seen (photo 5.1) and on the other, the relatively big germ, which contains the fat reserves.

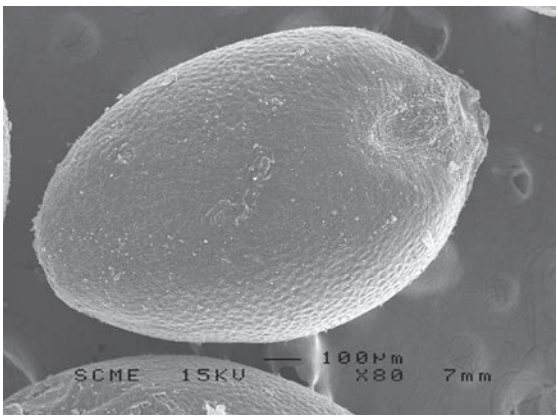


Photo 5.1. Hulled fonio grain (© G. Fliedel).

The undressed grain comprises three parts: seed coat, germ and endosperm (figure 5.2.).

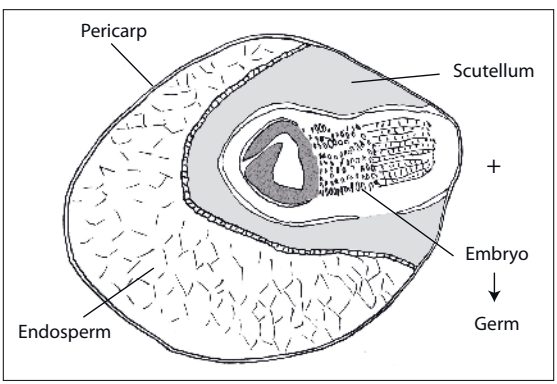


Figure 5.2. Schematic cross-section of fonio caryopsis (Cruz *et al.,* 2009).

The seed coat (figure 5.3) comprises:
– the pericarp, which corresponds to the coat of the "fruit" derived from the ovary wall.
– a proteinaceous layer or aleurone layer which represents the first layer of the endosperm.

Once eliminated, the seed coat will be part of the bran, rich in cellulose and in proteins.

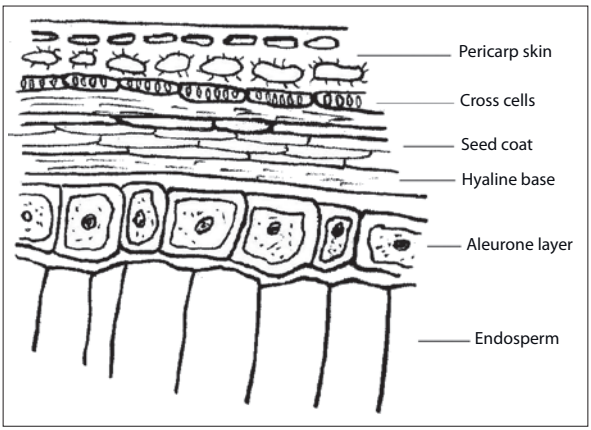


Figure 5.3. Structure of fonio pericarp (according to F. Heim de Balsac, 1931).

In 1931, F. Heim de Balsac described the caryopsis: "The cross-section of the caryopsis externally exhibits a row of flattened cells representing the epidermis of the pericarp (30 m in length, 6-8 m wide). Examined head on, these cells exhibit highly creased, thick walls, as we observe in nearly all the caryopses of Equatorial Gramineae".

The germ comprises the embryo and a cotyledon (or scutellum). It represents a reserve organ, rich in proteins and fats for the young plantlet. Once eliminated, the germ will form another part of the bran, rich in fats.

The endosperm represents the kernel of the grain, and corresponds to whitened fonio.

According to F. Heim de Balsac, the salient characteristics of fonio caryopsis are:
– absence of tabular cells;
– irregular proteinaceous area with a single row of cells;
– highly developed coat, with several layers of cells;
– starch grains reminiscent of rice, though distinguished by their rounded, expanded hilum, which is not in a star or Y shape.

More recently, the microstructure of fonio was studied using scanning electron microscopy (Irving and Jideani, 1997). The description is brief, but it confirms the following characteristics: the caryopsis comprises the layers of the pericarp and the testa surrounding the endosperm and embryonic tissues. The endosperm comprises a single layer of aleurone cells and starchy endosperm. The aleurone layer is thin over the whole endosperm, and thicker at the juncture between the embryo and endosperm. The aleurone cells contain droplets of fat and proteinaceous matter. The contents of the endosperm cells comprise simple polyhedral starch granules approximately 10 μm in diameter. As for rice or maize, the proteinaceous corpuscles are more abundant at the periphery of the endosperm and decrease towards the centre of the grain, unlike wheat, in which the distribution is more continuous.

Whitened fonio

Eliminating the bran (pericarp and germ) from the caryopsis yields whitened fonio; the form in which fonio is most often consumed (photo 5.2.). On average, the whitened fonio grain measures just 1.2 mm long, 0.7 mm wide and 0.5 mm thick. The density of the whitened grains is 860 to 870 g/l.

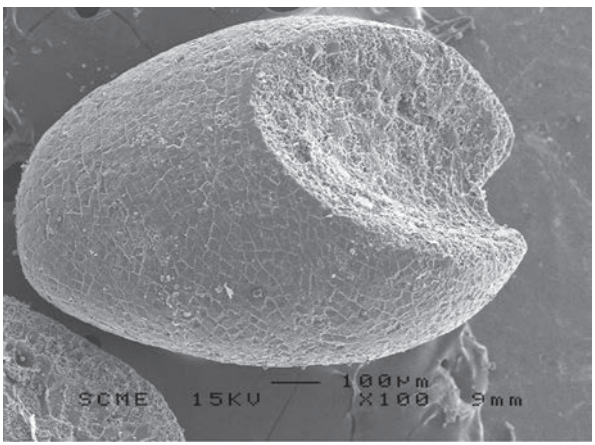


Photo 5.2. Whitened fonio grain (© G. Fliedel).

Thus, whitened fonio is the kernel of the grain, comprising cells filled with starch grains (photo 5.3.) and a weak proteinaceous network. The microscopic appearance of starch grains differs for each species of cereals. For fonio, the starch grains are polyhedrous, with a diameter of around ten micrometres: 4 to 12 mm (Heim De Balsac *et al.*, 1931), 2 to 13 mm (Jideani *et al.*, 1996) or 8 mm (Carcea and Acquistucci, 1997).

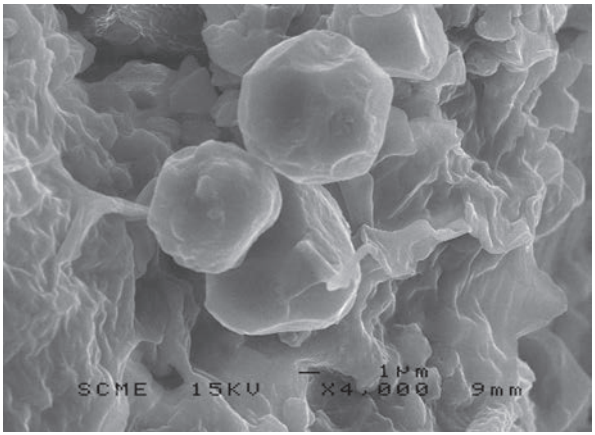


Photo 5.3. Fonio starch grains (© G. Fliedel).

Biochemical composition of fonio grain

The biochemical composition of hulled fonio and whitened fonio has been studied by CIRAD (Fliedel *et al.,* 2004).

Biochemical composition of hulled or whole fonio grain

In terms of its main components, hulled fonio has a composition comparable to those of other undressed cereals (table 5.1): 85% carbohydrates, 3.5% fats, 10% proteins and 1% mineral matter.

Table 5.1. Biochemical composition of whole fonio (compared to other cereals).

Cereals	Carbohydrates (% dry matter)	Fats (% d.m.)	Proteins (% d.m.)	Mineral matter (% d.m.)
Hulled fonio	84 - 86	3.3 - 3.8	9 - 11	1 - 1.1
Sorghum	84	3.5	11	1.2
Millet	83	4.0	12	1.2
Maize	83	4.5	11	1.3
Brown rice	86	2.5	10	1.4

Source: CIRAD (Fliedel *et al.*, 2004)

In closer detail, in terms of carbohydrates, hulled fonio seems slightly richer in starch (68% dry matter) than sorghum and millet (61 to 65% d.m.), though content may vary from 60 to 75% d.m. depending on the variety.

Amylose content is around 24% d.m. The total fibre content (cellulose, hemicellulose and lignin), around 7 to 8% d.m., is equivalent to that of millets and sorghums. The respective hemicellulose and cellulose content is similar, at nearly 3 to 4% d.m., while the lignin content remains low at 0.5% d.m. Free sugar content is around 1% d.m. The sugars present are mainly saccharose (0.7 to 0.8% d.m.), followed by glucose and fructose.

Fat content (3.3 to 3.8% d.m.) is comparable to that of sorghum (3.5% d.m.) and slightly less than that of millet or maize (4 to 4.5% d.m.), though greater than that of brown rice (2.5% d.m.). This is consistent with the comparison of the relative sizes of the germs in the various grains. More than 75% of fatty acids present are unsaturated fatty acids, represented above all by linoleic acid C18:2 (45%) and oleic acid C18:1 (31%), while the main saturated fatty acid is palmitic acid C16:0 (17%).

Hulled fonio contains slightly fewer proteins (9 to 11% d.m.) than millet, sorghum or maize (11 to 12% d.m.), but is still equivalent to brown rice (10% d.m.).

The amino acid composition (table 5.2) is balanced, although the lysine content is low, as in all cereals.

Table 5.2. Amino acid composition of whole fonio.

Amino acid	Content (% d.m.)	Amino acid	Content (% d.m.)	Amino acid	Content (% d.m.)
Aspartic acid + asparagine	0.68	Histidine	0.17	Proline	0.51
Glutamic acid + glutamine	2.16	Isoleucine	0.28	Serine	0.49
Alanine	1.24	Leucine	0.91	Threonine	0.34
Arginine	0.93	Lysine	0.19	Tryptophan	0.16
Cysteine	0.07	Methionine	0.34	Tyrosine	0.23
Glycine	0.08	Phenylalanine	0.47	Valine	0.52

Source: CIRAD (Fliedel *et al.*, 2004)

The energy value of hulled fonio is 1,470 kJ (approximately 350 kcal) per 100 g.

The main mineral elements in hulled fonio are phosphorus and potassium, as in other cereals, and whole fonio remains the cereal richest in sulphur. Table 5.3 sets out the mineral composition of whole fonio compared to other cereals.

Fonio and gluten

Fonio contains the four common protein fractions for cereals: albumins, globulins, prolamins and glutelins. In gluten intolerance, only certain prolamins have a proven toxicity, such as wheat α-gliadin, barley hordein and rye secalin. Other prolamins like that of sorghum (kafirin) or that of rice (orzenin) do not cause particular intolerances. Fonio, which is closer to millet, maize or sorghum than wheat (Mugnier, 2001), does not cause specific disorders since it must not have the particular sequence of amino acids which seems to be responsible for gluten intolerance in coeliac disease (see chapter 9). This assumption ought to be verified by specific research.

Table 5.3. Mineral composition of hulled fonio.

Mineral	Hulled fonio	Maize	*Sanio* millet	Sorghum
Mineral matter (% d.m.)	1.02	1.28	1.16	1.13
Macrominerals (% d.m.)				
Calcium (Ca)	0.022	0.012	0.017	0.014
Magnesium (Mg)	0.13	0.12	0.11	0.13
Phosphorus (P)	0.25	0.34	0.23	0.25
Potassium (K)	0.17	0.33	0.34	0.25
Sulphur (S)	0.16	0.12	0.12	0.13
Microminerals (ppm)				
Copper (Cu)	6.8	2.2	4.9	6.2
Iron (Fe)	38.8	33.4	82.5	94.6
Manganese (Mn)	21.6	9.4	13.0	20.9
Sodium (Na)	72.3	67.0	102.6	58.7
Zinc (Zn)	33.4	28.7	33.1	32.6

Source: CIRAD (Fliedel *et al.*, 2004)

Minerals are mostly concentrated in the peripheral layers of the grain, and so are largely eliminated during whitening.

Hulled fonio grain contains above all vitamin B1 (0.48 mg per 100 g d.m.), but this level drops considerably (0.06 mg per 100 g d.m.) after whitening.

Biochemical composition of whitened fonio grain

In terms of its main components, whitened fonio remains comparable to other processed cereals. As whitening has eliminated the bran (pericarp and germ), to leave just the kernel, the whitened grain is naturally richer in

carbohydrates (89 to 91% d.m.) and poorer in proteins (7 to 9% d.m.), fats (0.8 to 1% d.m.) and mineral matter (0.3 to 0.6% d.m.) than hulled fonio (table 5.4).

Table 5.4. Biochemical composition of whitened fonio (compared to other processed cereals).

Cereals	Carbohydrates (% dry matter)	Fats (% d.m.)	Proteins (% d.m.)	Mineral matter (% d.m.)
Whitened fonio	89 - 91	0.8 - 1.0	7 - 9	0.3 - 0.6
Husked sorghum	88	1.2	10	0.5
Husked millet	87	1.2	11	0.8
Husked maize	88	1.0	10	1.0
White rice	90	0.9	8	0.5

Source: CIRAD (Fliedel *et al.*, 2004)

In terms of carbohydrates, whitened fonio remains slightly richer in starch (80% d.m.) than sorghum and millet (66 to 70% d.m.), though levels may vary from 70 to 90% d.m. depending on the variety. The amylose content is around 28% d.m. Total fibre content (cellulose, hemicellulose and lignin) is logically lower (close to 4 to 5% d.m.), with respective levels of hemicellulose and cellulose of between 2 to 3% d.m. After whitening the grain, levels of simple sugars (glucose) drop to less than 0.1% d.m.

As whitening eliminates the bulk of the germ from the grain, whitened fonio has very low fat content (0.8 to 1% d.m.), similar to that of white rice, and less than that of husked millets, sorghums or maize (1 to 1.2% d.m.). The main fatty acids present remain unsaturated fatty acids, represented most of all by linoleic acid C18:2 (43%) and oleic acid C18:1 (31%), while the main saturated fatty acid is palmitic acid C16:0 (19%).

Whitened fonio contains slightly fewer proteins (7 to 9% d.m.) than millet, sorghum or maize (10 to 11% d.m.), but remains equivalent to white rice (8% d.m.). The amino acid composition is balanced (table 5.5.). Fonio remains the richest in sulphur amino acids. Its richness in methionine (0.42% d.m.) is practically double that of millet or maize (0.22 to 0.23% d.m.) and triple that of rice (0.15% d.m.).

The energy value of white fonio is 1,430 kJ (approximately 340 kcal) per 100 g.

Many minerals, often concentrated around the periphery of the grain, are largely eliminated during whitening. So in whitened fonio, mineral

Table 5.5. Amino acid composition of whitened fonio (compared to other processed cereals).

Amino acids	Whitened fonio	Whitened rice	Husked millet	Husked sorghum	Husked maize
Aspartic acid + asparagine	0.58	0.74	0.73	1.02	0.62
Glutamic acid + glutamine	2.33	1.35	1.27	3.48	2.25
Alanine	0.94	1.32	1.15	1.48	1.29
Arginine	1.00	0.44	0.63	1.50	0.80
Cysteine	0.08	0.05	0.04	0.08	0.09
Glycine	0.05	0.11	0.12	0.07	0.07
Histidine	0.16	0.15	0.18	0.28	0.26
Isoleucine	0.29	0.23	0.28	0.45	0.27
Leucine	1.00	0.56	0.76	1.98	1.34
Lysine	0.12	0.21	0.16	0.14	0.15
Methionine	0.42	0.15	0.23	0.24	0.22
Phenylalanine	0.52	0.35	0.39	0.68	0.47
Proline	0.56	0.27	0.59	1.12	0.88
Serine	0.48	0.35	0.37	0.59	0.47
Threonine	0.33	0.23	0.11	0.41	0.33
Tryptophan	0.13	0.11	0.11	0.15	0.04
Tyrosine	0.27	0.21	0.19	0.38	0.27
Valine	0.52	0.43	0.49	0.68	0.48

Source: CIRAD (Fliedel *et al.*, 2004)

content is distinctly lower than in whole fonio, except for sulphur, which seems present deeper in the grain. Hence whitened fonio remains richer in sulphur (0.16% d.m.) than other processed cereals (table 5.6.). Contrary to assertions sometimes made, fonio is not richer in iron than cereals like millets or sorghums.

In conclusion, whitened fonio is primarily a carbohydrate food whose biochemical composition is comparable to that of white rice, but it is particularly rich in sulphur amino acids such as methionine. Like white rice, it does not cause particular gluten intolerance.

Table 5.6. Mineral composition of white fonio (compared to other cereals).

Mineral	White fonio	White rice	Husked *sanio* millet	Husked sorghum	Husked maize
Mineral matter (% d.m.)	0.3	0.5	0.8	0.8	1.0
Macrominerals (% d.m.)					
Calcium (Ca)	0.01	0.01	0.01	0.01	0.01
Magnesium (Mg)	0.03	0.01	0.08	0.06	0.03
Phosphorus (P)	0.06	0.06	0.16	0.12	0.09
Potassium (K)	0.02	0.03	0.20	0.10	0.08
Sulphur (S)	0.16	0.08	0.10	0.11	0.12
Microminerals (ppm)					
Copper (Cu)	3.0	1.8	3.8	2.1	1.5
Iron (Fe)	27.3	23.4	59.8	65.0	18.9
Manganese (Mn)	4.9	12.2	8.2	8.5	2.5
Sodium (Na)	58.5	59.1	82.0	53.5	32.7
Zinc (Zn)	21.8	18.6	28.5	13.2	7.4

Source: CIRAD (Fliedel *et al.*,2004).

Hulling and whitening

It has already been stated that the crude paddy fonio grains obtained after threshing the spikes were not consumable in that state, and that they needed to be processed before cooking.

Flow diagram of processing

Like rice milling, fonio processing requires a sequence of two individual operations as shown in figure 5.4.:
– hulling, which removes the hulls from paddy fonio (raw fonio) to obtain hulled fonio or whole fonio (naked caryopsis);
– whitening, which eliminates the bran (pericarp and germ) from the hulled fonio to obtain white fonio.

Hulling alone is needed to make consumable whole fonio.

Measurements made in 1999 at the CIRAD laboratory (Montpellier) on five fonio varieties from Guinea showed that the hulls and bran represented respectively 23% and 9% of raw grain (Cruz, 2001).

The efficiency of fonio processing is given by the formulae below:

$$\text{Hulling yield: Yh} = \frac{\text{Quantity of hulled fonio}}{\text{Quantity of raw fonio}} \times 100$$

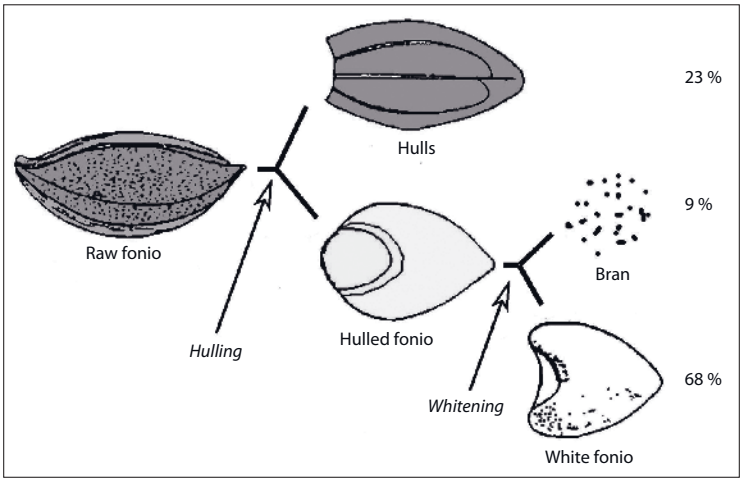


Figure 5.4. Flow diagram of fonio processing (Cruz, 2012).

$$\text{Whitening yield: Yw} = \frac{\text{Quantity of white fonio}}{\text{Quantity of hulled fonio}} \times 100$$

$$\text{Processing yield: Yp} = \text{Yh x Yw} = \frac{\text{Quantity of white fonio}}{\text{Quantity of raw fonio}} \times 100$$

From raw fonio, the potential yield for hulled fonio and white fonio respectively are: Yh = 77 % and Yp = 68 %.

Traditional hulling

Fonio hulling and whitening are operations traditionally carried out by women using wooden pestles and mortars (figure 5.5). To obtain a hulled fonio for sale purposes, the women perform three or four successive grinding operations, with winnowing in between. A final grinding is then carried out to obtain whitened fonio.

Observation of traditional hulling in the village of Kondia, near Ségou in Mali, made it possible to characterise the various steps in fonio grinding (Cruz, 2001). The family visited, comprising five households, produces fonio on an approximately 2 ha field, and usually grows two varieties, known as "Souroukou Fini" and "Fini". In September 1999, the producer was able to harvest nearly 2,600 kg of grain, which was stored in bulk in a large banco granary. Despite the good yield obtained, of 1,300 kg/ha, this family did not wish to continue growing fonio because of the processing difficulties. It was five women from the family who hulled the fonio, using Fini variety grains.

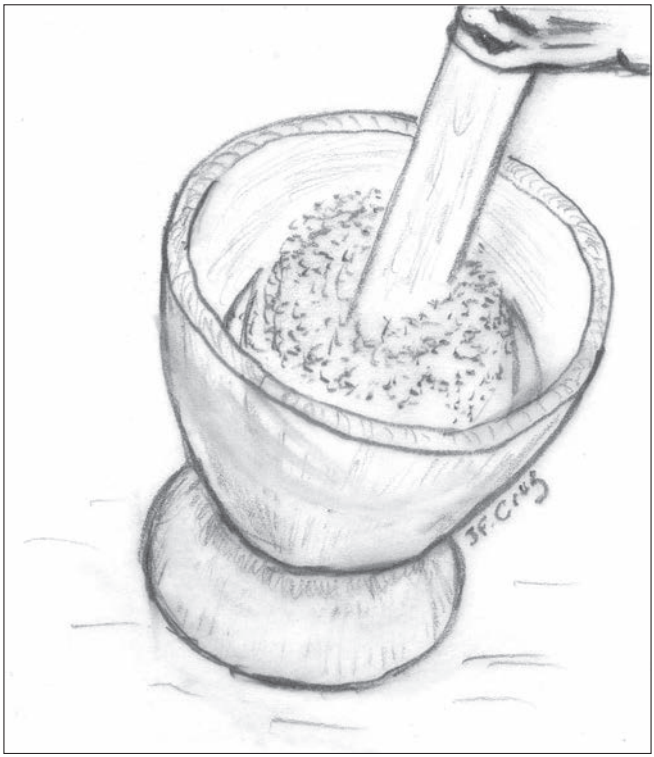


Figure 5.5. Traditional hulling of fonio with a pestle and mortar (J.F. Cruz).

Cleaning raw grains

The first phase of the process consists in cleaning the batch of grains taken from the granary. The contents of a gourd, approximately 6 kg, are sieved a first time by the women to eliminate coarse impurities (straw, stems, pebbles) using a 2 mm mesh sieve known as a "*bassi témé*". To remove the fine impurities (earth, grit, dust), it is then cleaned a second time using a fine 1 mm mesh sieve known as a "*mougou témé*". In the present case, fonio stored in the granary was relatively dirty, since the impurity level was 11.7%.

Hulling and winnowing the grains

After cleaning, the five women took turns carrying out the various hulling operations. The first hulling, lasting five minutes, is carried out by two women on the same pestle. This is followed by the first winnowing. The women then carry out three other hullings, with winnowings in between. Fonio obtained after the fourth hulling-winnowing is often known as

"pre-hulled fonio", and is sold as-is on local markets at a price of around 300 FCFA/kg (€0.46/kg) in normal periods, and 375 to 400 FCFA/kg (€0.57 to 0.61/kg) in the lean season.

The yields of the various operations are given in table 5.7 below:

Table 5.7. Yield measurements for the various traditional hulling operations.

Operation	Duration (mins)	Quantity of product collected (g)	Yield (%)
Taking fonio from the granary		6,000	
Cleaning	10	5,300	
1st hulling and winnowing	5	4,700	88.7
2nd hulling and winnowing	6	4,250	80.0
3rd hulling and winnowing	10	3,900	73.6
4th hulling and winnowing	8	3,700	69.8
5th hulling-husking (whitening)	4	3,600	68.0

Source: CIRAD (personal notes of J.F. Cruz)

The so-called "pre-hulled" fonio obtained after the fourth hulling-winnowing should be the same as whole fonio, but the yield obtained from traditional hulling (69.8%) proves relatively low compared to the potential yield, which should be around 77% (figure 5.4). In reality, the fourth hulling carried out here already seems to correspond to a first whitening, and so it would be more reasonable to call the grain obtained "pre-whitened fonio" rather than "pre-hulled" fonio. After the fifth hulling, which corresponds to real whitening, the observed yield of 68% is equal to the potential processing yield.

The total duration of the operation carried out by the five women was approximately one hour. The unit throughput of traditional hulling remains very low, barely exceeding 1 kg/h. Manual hulling with a pestle and mortar is still considered highly laborious by the women, who are prepared to pay 15 FCFA/kg to have others carry out this operation.

In Guinea, manual hulling is also carried out by women using a pestle and mortar. If the fonio is intended for family consumption, the sequence of operations is conducted with care until the grains whiten; which limits the average throughput of the women to 1 to 1.5 kg per hour. The experienced women who carry out hulling professionally are generally more efficient, as they can process 2 to 3 kg per hour, but they often stop the operation before the grains are really whitened. The cost of the service in 2002 was 150 FG (Guinean franc) per 1.3 kg measure, i.e. approximately 40 FCFA/kg (€0.06/kg) at the time.

In Burkina Faso, fonio hulling is traditionally carried out with pestle and mortar by groups of women. There too, it consists in a succession of three or four grinding operations separated by cleaning, which is generally limited to simply winnowing. The hulling work can be outsourced, at a cost of between 15 to 30 FCFA/kg. The hulled product intended for sale on the market is sometimes mixed with ash to improve its storage properties. It is rarely cleaned by the producers themselves, who consider this job to fall to the end women processors.

In all the countries, traditional hulling with pestle and mortar is considered by the women as a long and exhausting job. It requires great effort for the small quantities obtained, and generates a lot of dust (hulls, etc.) which cause severe eye itching. Given these conditions, fonio industry operators, and mainly women, are most of all calling for the mechanisation of hulling.

Washing and degritting before cooking

After processing and winnowing, there are often bran and dust particles left stuck on the surface of the fonio grains. The women wash the whitened fonio several times. The grains are poured into a large gourd filled with clean water, and then mixed by hand to properly detach the impurities. The fonio grains sink to the bottom of the gourd, while the fine particles float, and are eliminated by pouring the surface water into another receptacle. The dirty water, filled with bran and various impurities, is then disposed of, or sometimes given to animals to drink. This washing operation may be repeated several times, depending on the cleanliness of the grains.

Then the women painstakingly eliminate the grit present in fonio. During the various post-harvest operations and in particular when threshing the sheaves on the ground, impurities – most often comprising grains of sand or laterite – may be mixed with the fonio grains. The subsequent winnowing and sieving operations eliminate these fine impurities in part, but not the grains of grit, which are the same size as fonio grains (Goli *et al.,* 2014). Like pebbles in lentils, the presence of grit represents one of the main quality problems in fonio.

The pre-washed fonio is soaked in clean water. The mixture is then slowly poured into a larger receptacle (gourd or basin). The lighter fonio grains are carried with the transferred water, whereas the heavier grit particles remain at the bottom of the first gourd (photo 5.4). This traditional "degritting" operation is very much akin to gold panning. The quality of separation depends primarily on the know-how of the operator, who repeats the operation several times until she considers that there is no grit left mixed

in the grains. It often takes four degritting operations to obtain fonio free from grit. The washed grains are then placed in small quantities through a fine sieve, or a dishcloth, and spun dry with a vigorous arm swinging action. Whitened fonio washed and dried in this way is ready to be cooked, most often steamed, and prepared using various recipes.

Photo 5.4. Separation of grit present in fonio (© J.F. Cruz).

The women processors tend to say that washing and degritting are difficult operations which demand "a lot of patience and a lot of water." Some of them consider that it takes nearly 10 l of water to wash and degrit 1 kg of fonio, and so they deem fonio "the best groomed" cereal (Leplaideur *et al.,* 1994). This high water consumption is a real constraint in regions where resources are scarce. Furthermore, the absence of recycling or treatment of waste water filled with organic matter is becoming an environmental concern, in particular on small processing units which produce tens of tonnes of fonio every year. This is currently one of the major problems of the industry.

Fonio field in the Fouta Djalon in Guinea (© J.F. Cruz).

Fonio plants (© J.F. Cruz).

Fonio racemes (© J.F. Cruz).

Fonio grains (© J.F. Cruz).

Comparison of different cereal grains size (© J.F. Cruz).

Grains of fonio (*Digitaria exilis*) and wild fonio (*Panicum laetum*) (© J.F. Cruz).

Ox-draw ploughing in Mali (© M. Havard).

Development of fonio plantlets (© B. Daho).

Manual weeding of fonio (© B. Daho).

Fonio fields on a plain and slopes in Fouta Djalon (© J.F. Cruz).

Reaping of fonio with a sickle (photo J.F. Cruz).

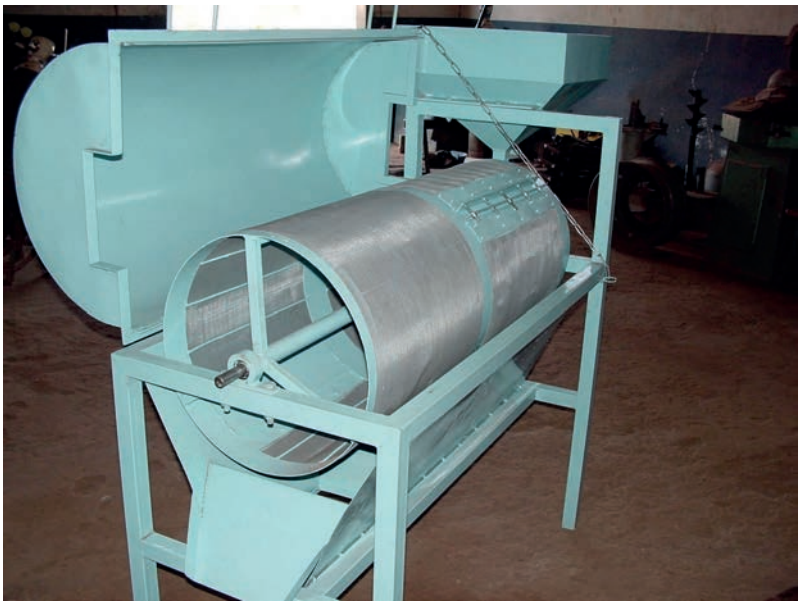
Transport of fonio sheaves after harvest (© J.F. Cruz).

Fonio producer in Guinea (© J.F. Cruz).

Traditional rod threshing of fonio by men (© J.F. Cruz).

Traditional threshing by women trampling (© E. Vall).

Thresher ASSI modified for the mechanical threshing of fonio (© J.F. Cruz).



Rotary screen for the fonio cleaning (© M. Rivier).

GMBF fonio huller with electric motor (© D. Dramé).

Demonstration of the GMBF huller in a village in Mali (© D. Dramé).

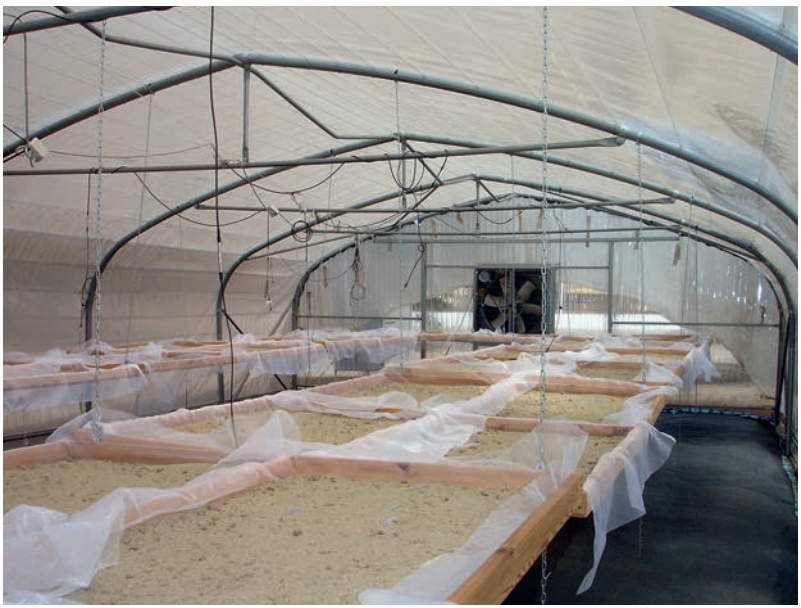
Washing of the fonio grains after hulling and whitening (© J.F. Cruz).

The degritting or separation of the sands of whitened fonio (© P. Thaunay).

Traditional precooking of fonio (© J.F. Cruz).

Lump breaking and sieving after fonio precooking (© J.F. Cruz).

Natural drying of precooked fonio on a table (© J.F. Cruz).



'CSec-S' greenhouse dryer for solar drying of precooked fonio (© J.F. Cruz).

Whitened fonio sold in the market of Miti in Guinea (© J.F. Cruz).

Whitened fonio retail market of Labe in Guinea (© J.F. Cruz).

Sachets of precooked fonio sold in Bamako, Dakar and Ouagadougou (© J.F. Cruz).

Parboiled or precooked fonio packages sold in France (© J.F. Cruz).

Traditional dish of fat fonio (© J.F. Cruz).

Fonio cakes (© J.F. Cruz).

6. Improving post-harvest technologies

The description of the various traditional practices after fonio harvesting shows how they are often exhausting for farmers and their families. Thus many producers are tempted to abandon this cereal in favour of food crops judged less demanding, as is the case for example in northern Benin, where fonio is gradually being replaced by maize. So improving fonio post-harvest technology is essential in order to prevent this industry from disappearing, and to maintain, wherever possible, a diversity in agricultural production to provide as solid a base as possible to cope with climate change.

An interest in mechanising fonio post-harvest operations is nothing new, since already in 1905, L. Renoux and P. Dumas mentioned the mechanical threshing of fonio: "We should note that grinding of fonio by the native method is a lengthy operation. We saw it being carried out very rapidly using a small thresher, equipped with shakers which simultaneously eliminated the need for winnowing."

Later, in 1929, Émile Perrot, a French chemist and botanist, wrote in the report of his mission to Guinea that the chief of the Dalaba district "harvested superb vegetables, rice, millet and fonio." Regarding fonio he specified: "This small grain is in such abundance that the village can export 60 to 80 tonnes, and this chief, an intelligent and rich man, wanted to give me 20,000 francs to send him a hulling machine: as the women can no longer find the time, as in the past, required for hand grinding. Naturally, I declined the offer, as no machine has yet been designed for this purpose, however I did promise him to look into the issue."

Then, in a note, he specified that in the end he kept his word, and sent the governor "two fonio hulling machines, operating with arms."

What were these different machines like? No precise description has ever been made, and no reference to any copies reproduced or distributed by local craftsmen exist, since the manual techniques still prevail everywhere to this day.

There may have been other sporadic attempts, but the very first international fonio post-harvest technology improvement project appeared only in 1999. Under the aegis of the FAO Intergovernmental Group on grains, and funded by the CFC (Common Fund for Commodities), a United Nations body, this first regional project on fonio was coordinated by CIRAD and conducted in

collaboration with the national research institutes of Mali (Institute for Rural Economy), Guinea (Guinea Agronomic Research Institute) and Burkina Faso (Applied Sciences and Technology Research Institute). The project brought together scientists from various fields: mechanisation, process engineering, food technology, crop science, social sciences, etc. and promoted private sector participation, and in particular local craftsmen (manufacturers) and small processing companies.

This was the framework in which various technical studies were conducted to mechanise the main post-harvest operations (Cruz and Dramé, 2005).

Improving threshing techniques

Manual threshing has been described as a highly laborious activity demanding lots of work and personnel. Along with reaping, it is the agricultural operation which requires the most labour, i.e. approximately 15 to 20 man-days per hectare (Daho *et al.,* 2007). The time between harvesting and threshing, which is sometimes relatively long because of lack of time and manpower, can cause post-harvest losses and affect the quality of the grain, depending on the sheaf storage conditions. Because of its laboriousness, threshing is the operation for which the men want machines tailored to their requirements. This demand has justified mechanisation of threshing being considered a priority within the fonio post-harvest technology improvement project.

Mechanical threshing principles

For cereals, the essential role of the threshing instrument is to separate the grains from the spikes or panicles. In a mechanical thresher, this result is obtained by two simultaneous actions: thresher percussion and friction of the stems in a thin gap between the thresher and counter-thresher. The usual different types encountered are bar threshers, small in diameter, used for threshing compact spikes (maize, millet), and toothed/finger or looped threshers (figure 6.1), bigger in diameter, for threshing straw cereals (rice, wheat). Fonio is a straw cereal, and so it was decided to adapt a rice thresher to threshing fonio.

Adapting an Irri thresher to fonio threshing

The Irri thresher, developed in the 1970s by the International Rice Research Institute in the Philippines, is one of the most widely distributed axial flow threshers in Asia for threshing rice. In the early 1990s, it was adapted in Africa to become the Assi thresher, developed in Senegal by the association of the same name, bringing together the following partners: Adrao

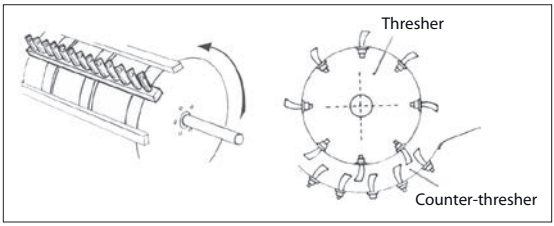


Figure 6.1. Diagram of finger thresher and counter-thresher (according to Ceemat doc.).

(Association for agriculture development in West Africa), Saed (National corporation for the development and exploitation of the River Senegal delta lands), Sismar (Senegal industrial corporation for agricultural equipment) and Isra (Senegalese Institute for Agricultural Research). Irri threshers come with or without a cleaning system. The absence of a cleaning device greatly simplifies the machine and reduces the manufacturing cost, but makes manual cleaning of the grains necessary.

The Assi thresher used for fonio was manufactured by Sismar in Senegal, and then adapted to fonio in Guinea. It is a stationary thresher, driven by a 14 hp (10.3 kW) diesel engine, and comprising an axial flow finger thresher and a ventilated cleaning shelf (figure 6.2). The structure is mounted on a wheeled chassis which can be towed by motorised machinery. The main dimensions of the machine, without the drawbar, are: 2 × 2.6 × 1.5 m (L × w × h).

To adapt this rice thresher to threshing fonio, no fundamental rectifications were made to the structure of the machine. Only the following modifications were made:

– Change of fan pulley to reduce the fan speed: replacement of 100 mm pulley by a 125 mm pulley, with a tensioner fitted to ensure belt tension.
– The rotation speeds of the moving parts and the settings are as follows:
  • Thresher rotation speed: 710 to 785 rpm.
  • Fan rotation speed: 520 to 560 rpm.
  • Worm screw rotation speed: 415 to 480 rpm.
  • Ventilation louver aperture: 1.5 to 3.5.
– Distance set between finger tips and the counter-thresher reduced from 10 to 8 mm.
– Length of screen connection rod reduced.
– Drawbar adapted to enable the thresher to be towed by a vehicle.
– Modifications to cleaning system:
  • Upper grille: metal plate with 3 mm perforations, grille extended by 450 mm.
  • Lower grille: 1 mm lattice fitted under the lower deflector.

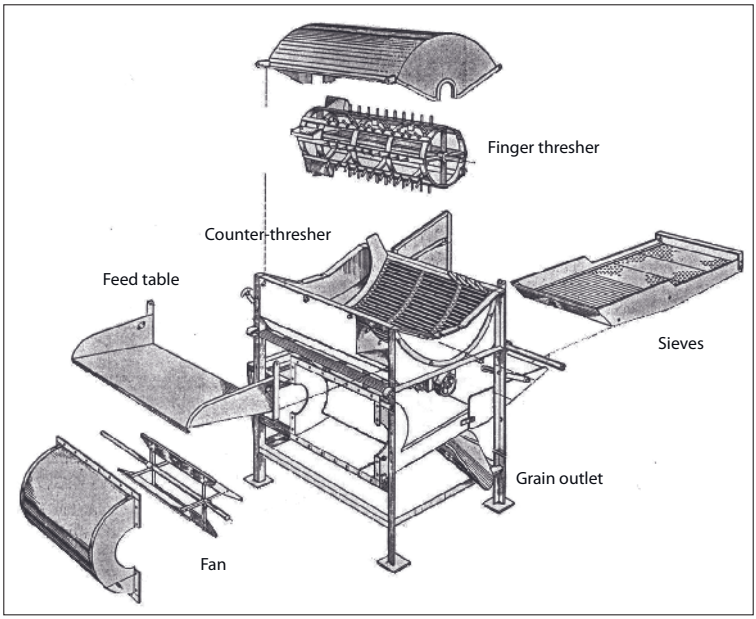


Figure 6.2. Cutaway diagram of a rice thresher (according to Irri doc.).

Operation and performance of the Irri thresher adapted to fonio threshing

The fonio sheaves are inserted manually into the threshing cage on the feed shelf. The threshed grains and fine straw passes through the counter-thresher and drops onto the cleaning grilles, while the coarse straw is ejected by the thresher at the front of the machine. The cleaning grilles comprise an upper plate with 3 mm perforations and a lower grille with a 1 mm mesh. Under the double action of shaking and ventilation, the grain is separated from the fine straw on the cleaning grilles. The clean grain is collected at the main outlet on the side of the machine, while the rejects are collected from a secondary outlet, and the impurities at the rear of the machine.

Operating tests were conducted from 2002 to 2004 in Fouta-Djalon (Guinea), in the village of Seghen, and then in various villages of the sub-prefectures of Garambé and Hafia near Labé. To ensure good machine efficiency, it is essential to thoroughly dry the sheaves between cutting and threshing, to reduce the moisture content of the straw. The best throughputs were obtained with stack drying for 3 to 8 days. With the modified Assi thresher, high threshing throughputs are achieved, varying from 250 kg/h to 300 kg/h. The quality of threshing is rated as satisfactory, since little grain remains unthreshed, and

the fonio obtained is very clean. Fonio producers who participated in the tests rated the machine's performance highly.

An estimate of the cost of motorised threshing with an Assi thresher was made in April 2004, based on the hypothesis of a tonnage of approximately 100 t of threshed fonio per year and 120 days of operation (approximately 400 hours of work per year, at an average throughput of 250 kg/h). Assuming an investment of 13.6 million FG (approximately 3.8 million FCFA at the time), depreciated over the machine's service life of eight years, this simulation led to a threshing cost of around 54 FG (or 15 FCFA) per kg of threshed fonio; which, under local conditions, is equivalent to the cost of manual threshing. Within the expenditure, the share of machine depreciation represents 32%, repairs 25%, labour (three operators) 23%, and fuel and lubricants 19%.

Threshers are relatively expensive equipment in terms of investment, and normally they need to be purchased by village associations or private entrepreneurs who can make a profit by hiring them out. The machine has a daily capacity equivalent to the average production of two or three producers. So it must be located in places where it can be of service to the biggest possible group of producers, in order to limit the time and costs required to move it to another production location.

Because of its size, the Assi thresher is very well suited to easy-access plain zones, whereas in mountainous zones, it is more difficult to transport. There, the focus should be on using lighter threshers. This is the case in western Mali, in the rough terrain of the Kéniéba region south of Kayes, where Votex "ricefan" rice threshers (figure 6.3), manufactured by Socafon (official cooperative company of artisan blacksmiths of Niger), have been tested in certain villages by the producers' organisation Benkouto, with the support of the NGO "Le Damier". In 2015 the "ricefan" thresher was also tested in Guinea but results were not convincing.

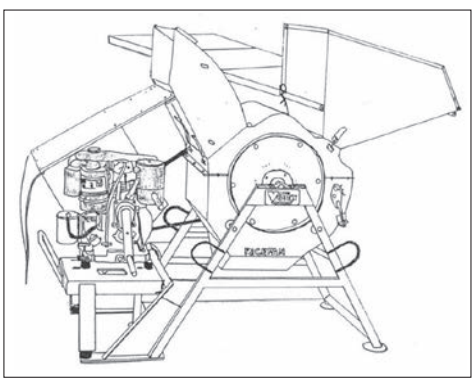


Figure 6.3.
"Votex" thresher
(according to FAO doc.).

Improving cleaning/sorting techniques

During the various post-harvest sequences, starting with the threshing operation, the good grain can be contaminated by various foreign substances. Mixed with the raw material, these impurities can be mineral (pebbles, grit and metal particles), plant (straw, foreign seeds, hulls, bran, etc.) or animal (insects, faeces, etc.) in nature, and must be eliminated in order to obtain a high-quality processed product. Furthermore, mineral matter, which is generally harder, causes premature wearing of the processing machines. The grains are often cleaned simply by winnowing to eliminate light particles such as straw, and then by sifting through sieves of various meshes, to separate coarse or very fine impurities such as grit. Cleaning fonio commonly poses more problems than for other cereals, because of its small grain size. So washing is often essential in order to clean the raw material, but most of all to separate grit from the processed products. Technical advances were proposed as part of the fonio post-harvest technology improvement project.

Using winnowers or rotary screens

The usual equipment used for cleaning cereals are winnowers and rotary screens, which can be manually driven or motorised. The winnower is a simple cleaner comprising two superimposed grilles, driven in a to-and-fro movement, with a fan-generated air current flowing through. The upper grille retains coarse impurities, while the lower grille lets through very fine particles; the good grain is always retained between the two grilles, while the ventilation is able to eliminate the light impurities (figure 6.4). The

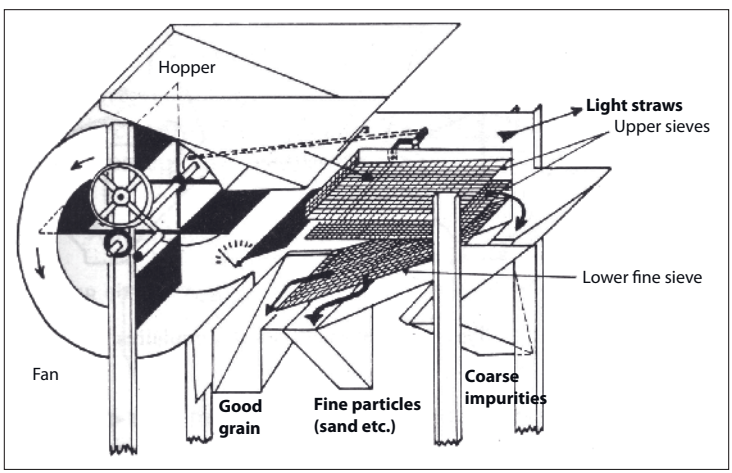


Figure 6.4. Winnower (according to CIRAD/Ceemat doc.).

winnower is versatile, and has the advantage of operating even with products high in straw. Its operating principle, consisting in to-and-fro movement of the grilles, does however make it fragile to use, and so the more robust rotary cleaners are often preferred.

The rotary screen is a very simple piece of equipment, comprising a feeding hopper and a cylindrical screen with two successive grilles. The first grille, with small perforations, lets through very fine impurities (dust, grit), while the second grille lets through good grain and retains coarse foreign bodies, which are eliminated at the end of the machine (figure 6.5). The equipment is on a slightly tilted axis, to enable the product to flow through naturally while the machine operates (Cruz *et al.,* 2014). It is driven round via a crank or a small engine. The good grain and various impurities are collected in containers placed on the ground under the machine.

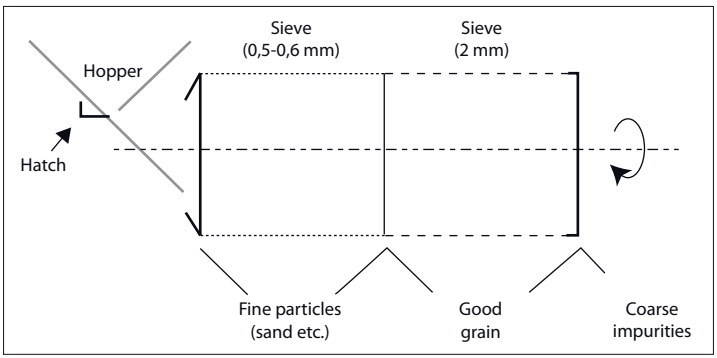


Figure 6.5. Diagram of rotary screen (C. Marouzé, 2005a).

As part of the fonio post-harvest technology improvement project, various rotary screen models of varying length were manufactured in Mali and Burkina Faso, and tested by private partners. Tests showed that the manual rotary screens cleaned raw fonio and hulled fonio well, with throughputs of 150 to 300 kg/h. Local women processors are satisfied with this equipment, which they deem highly efficient for sifting fonio. There are several possible upgrades to the equipment: versatility, electrical motorisation, etc. (Marouzé et *al.*, 2005a). With a purchase cost of 500,000 FCFA, five-year depreciation and for cleaning 50 to 100 t per year, the cost of using the manual screen appears to vary between 2 to 4 FCFA/kg, depending on machine type.

Development of a winnowing channel

The winnowing channel, designed by CIRAD in collaboration with the IER in Mali (Marouzé *et al.,* 2005b), comprises a vertical nozzle with

upward air flow, in which the contaminated product to be cleaned is inserted at mid-height. The light particles are drawn in by the air flow, and collected in a cyclone. The grains and heavier particles drop into a lower part of the channel (figure 6.6). The winnowing channel is a versatile piece of equipment which can be used for winnowing various grains (cereals, legumes, and oilseeds). Tests conducted by a processing company in Mali achieved a throughput of 130 kg/h with hulled fonio, and 300 to 600 kg/h with husked millet, maize or cowpea. The winnowing channel can also be placed at the outlet of the GMBF huller (see below). For an investment of 400,000 FCFA and an eight-year depreciation of the equipment, the cost of mechanical winnowing appears to be around 3 FCFA/kg (for 65 t of winnowed product in 200 days of operation).

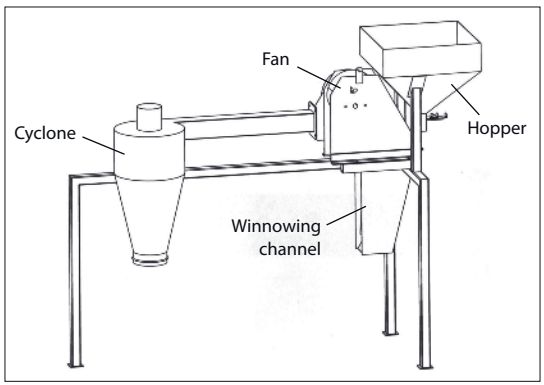


Figure 6.6. Representation of the winnowing channel (P. Thaunay).

Other cleaning operations: washing and degritting

After hulling the fonio, there are many impurities (bran, grit) left mixed with the grains. Use of conventional cleaners is not always efficient, since on the one hand the bran particles, often oily, remain stuck to the surface of the grains, and are difficult to separate simply by winnowing or sifting, and on the other hand the grit particles the same size as the fonio grains cannot be eliminated simply by sifting. Washing operations and degritting operations are often essential for eliminating these various impurities and obtaining a quality whitened fonio.

Design of a washer

A washing device was designed by CIRAD for laboratory testing in France and Mali. The bran is separated in a washer comprising a cylinder with an angled propeller (figures 6.7). The cylinder is fed with grains to be washed

in the bottom part, and with washing water in the top part. As it rotates, the propeller cylinder mixes the grains and lifts them up to the top part. The injected water, which gradually accumulates impurities, is evacuated via the bottom part. To wash the fonio, another technique has been tested most recently involving the use of "concrete mixer" type washers.

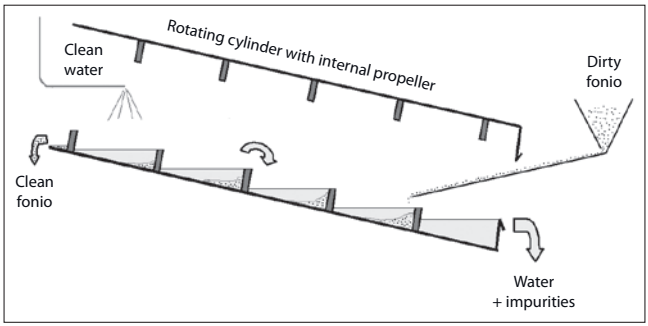


Figure 6.7. Schematic of a washer (according to C. Marouzé).

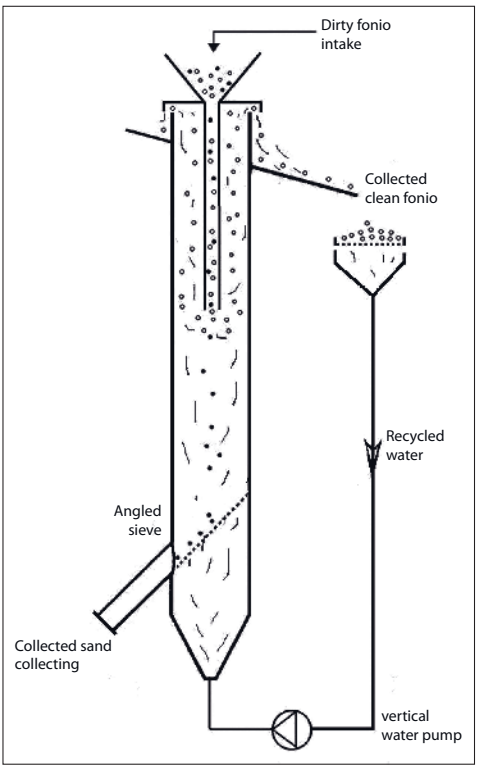


Figure 6.8.
Schematic of
the "hydrolift" degritter
(according to C. Marouzé).

Design of a "hydrolift" degritter

A so-called "hydrolift" degritter was designed by CIRAD for laboratory testing in France and Mali. The prototype hydrolift degritter comprises a vertical tube fed with water in the bottom part by a pump (figure 6.8). Whitened fonio containing impurities (grit) is inserted half-way up via a central tube, with a water stream which helps the grain descend. The main water flow is set so that the fonio seeds are driven by the water flow. After overflowing in the top part, the seeds are separated from the water and collected by a sieve. The heavier grit particles drop down in spite of the water flow, and are caught by an angled grille and directed toward an adjacent cylinder, where they are collected at the end of the operation. The dimensions of the equipment are as follows:

– Column diameter: 190 mm.
– Column height: 850 mm.
– Diameter of central tube: 110 mm.
– Length of plunger feed tube: 450 mm.

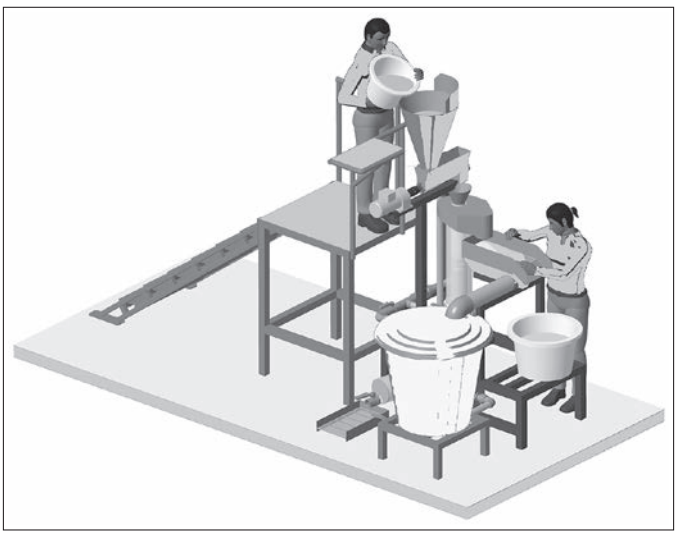


Figure 6.9. Diagram of hydrolift (P. Thaunay).

In 2007, an initial prototype was tested in Mali which was able to eliminate up to 90% of sand. In 2015 and 2016, improved machines (figure 6.9) were built by CIRAD, by manufacturers Imaf in Mali, and by Soldev in Burkina Faso, and installed in small companies in Bamako (Mali), in Bobo Dioulasso (Burkina Faso) and in Kédougou (Senegal). Operating test results showed that the performance of the machines was satisfactory with average throughput of 100 kg/h (Cruz, 2016).

Improving processing techniques – mechanisation of hulling

Traditional hulling, carried out with a pestle and mortar, is a very laborious job, which produces just 1 to 3 kg per hour, depending on the skill of the operators. Mechanisation of fonio hulling is often viewed as a priority among women. Some attempts have been made in the past by private projects or workshops, in particular in Guinea, to develop machines suited to the requirements of women farmers and processors, but without convincing results.

The "Sanoussi" huller

One of the first machines manufactured was the "Sanoussi" huller, designed and manufactured in Senegal in the early 1990s. The documentation shows that the machine comprises a tapered metal chamber containing two rotating vanes. The bottom of the chamber, angled to enable drainage, is covered with a granular surface which facilitates friction of the grains and elimination of peripheral layers. The vertical shaft bearing the vanes rotates at a speed of around 1,300 rpm. It is linked by a belt-pulley system to a 1.5 kW (1,500 rpm) electric motor. The machine works in bursts, with batches of 2.5 to 3 kg of fonio for processing.

Photo 6.1. Tests on the Sanoussi huller at IER (Mali) (© J.F. Cruz).

In the early 2000s, operating tests in the laboratory were conducted on the Sanoussi huller by the Benin National Institute for Agricultural Research (INRAB) and the Malian Institute for Rural Economy (IER) (photo 6.1). Results showed that the machine sometimes performed less well than was declared; the throughputs achieved were just 10 to 20 kg/h instead of the claimed 35 kg/h. The processing yield achieved was just 60%, and the quality of work is often deemed insufficient by operators, since many grains are not correctly hulled. This machine has the particular merit of having been the trailblazer, but many women processors have now abandoned it, deeming it outmoded due to its modest technical performance.

"GMBF" huller

Taking inspiration from the "Engelberg" rice huller, a specific huller was designed for fonio processing. In the early 2000s, an initial prototype was made and tested by CIRAD in Montpellier to validate the principle of hulling and produce design plans with a view to local manufacture in Africa (Marouzé *et al.,* 2008). This equipment was known as the "GMBF" (Guinea, Mali, Burkina, France) to commemorate the collaboration of the various research institutes which took part in its creation (Cruz *et al.,* 2014).

Description of the GMBF huller

This artisanal huller primarily comprises a ribbed metal cylinder rotating inside a metal tube which forms the shell of the machine (figure 6.10). The hulling chamber is equipped with an adjustable metal bar inside the shell, which acts as the brake, and at the outlet a flow-setting flap (Marouzé *et al.,* 2005c). The feeding hopper has a capacity of 35 kg. Hulling and whitening of fonio is carried out by friction of the grains against each other. The brake can be adjusted up or down to control the friction phenomenon (figure 6.11). The mixture of hulled and whitened grains and by-products (hulls and bran) can be removed via the adjustable outlet hatch. Its setting determines the intensity of hulling or whitening.

The machine can be used either as a huller only, to obtain hulled fonio from raw fonio, or as a whitener only, to obtain whitened fonio from hulled fonio, or finally as a huller-whitener to obtain whitened fonio from raw fonio. In the latter case, the processing may be carried out in a single run, or two successive runs if you want to collect the by-products (hulls and bran) separately.

To obtain a clean product, a winnowing channel can be placed at the outlet of the machine (figure 6.12). The mixture of hulled and whitened grains and by-products (hulls and bran) drops into the winnowing channel. Fine impurities are drawn in by the air flow, and collected on a cyclone, whereas the grains drop by gravity into a container placed under the winnowing channel.

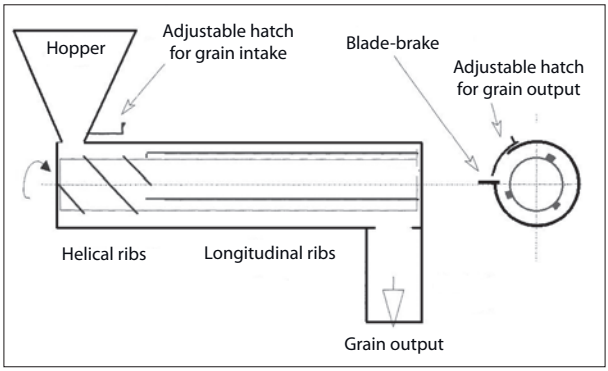


Figure 6.10. Schematic diagram of the GMBF huller (according to Marouzé *et al.*, 2005c).

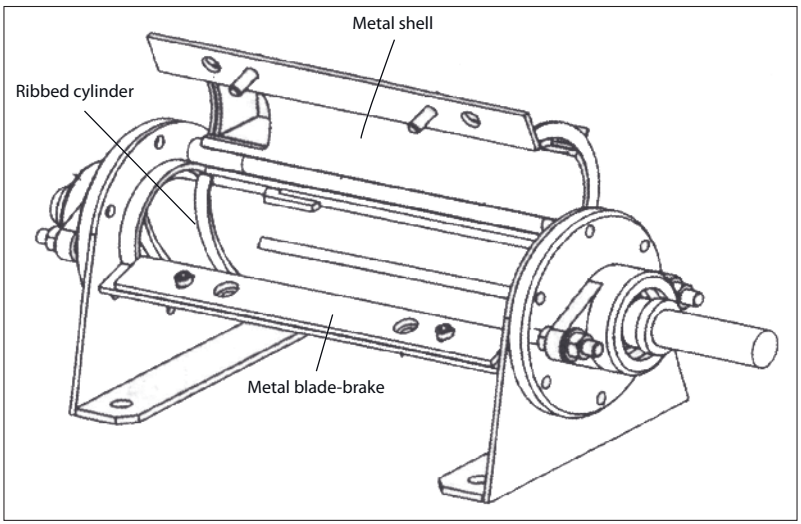


Figure 6.11. GMBF huller, with hulling chamber open (P. Thaunay).

The GMBF huller can be driven by a 5.5 to 7.5 kW electric motor for use in urban zones, or an 8 to 10 kW diesel engine for use in non-electrified rural zones. The general characteristics of the equipment are as follows:
– Space requirement (L × w × h): 1.25 × 0.75 × 1.40 m (figure 6.13).
– Electric version with cyclone: 2.10 m in length.
– Diesel version: 1.8 m in length (without cyclone) and 2.70 m (with cyclone).
– Weight of the assembly: approximately 200 kg (electric motor) and 320 kg (fuel engine).

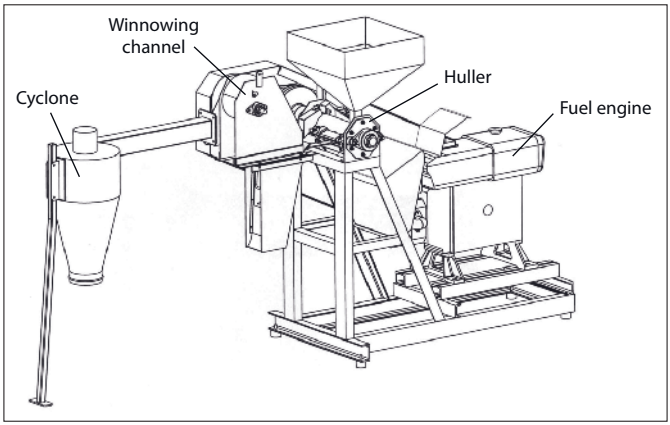


Figure 6.12. GMBF huller with winnowing channel and fuel engine (P. Thaunay).

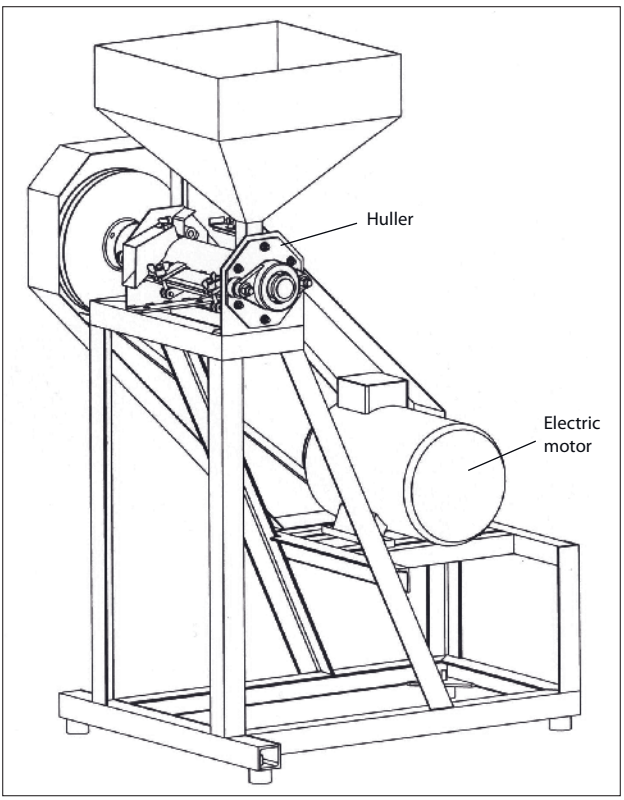


Figure 6.13. GMBF huller only, electric version (P. Thaunay).

Performance of the GMBF huller

In 2002, the first three machines were built by a manufacturer in Bamako and sent to each of the partner countries of the fonio post-harvest technology improvement project to be tested by private operators. This equipment was installed in rural and urban zones with small companies in Bamako (Mali), in Bobo Dioulasso (Burkina Faso) and in Labé (Guinea). It was used to process a few tens of tonnes of fonio, achieving the following performance levels:

Huller throughputs:
– 50 to 100 kg/h for hulling-whitening in two runs, with an overall processing yield of around 65%.
– 100 to 120 kg/h for hulling only, with a hulling yield of approximately 75%.
– 100 to 150 kg/h for whitening, with a whitening yield of close to 90%.

The huller's throughput can rapidly deteriorate with wear on the working parts. The brake blade appears worn after processing 10 to 12 t of product, whereas the ribs on the rotor are blunted after 40 t. These worn parts must be rapidly replaced or reconditioned before they completely deteriorate, since excessive wear leads to other forms of deterioration and increases operation costs. To increase the durability of the machine and its service life, plans have been made to equip the chamber of the latest prototype with a removable "cup" that acts as a wearing part. The importance of correctly cleaning the raw material is clearly apparent, since the greater the grit content of the raw material, the faster the wear on the equipment.

All the tests conducted on the various prototypes were satisfactory. The quality of the processed products was rated very highly by the local operators, and in particular by the women (Cruz, 2004). After seeing the machine in operation, many women processors did not want to go back to manual processing, and some of them said: "We've thrown away the pestle, and we never want to pick it up again." In culinary terms, the quality analyses of hulled fonio and whitened fonio with the GMBF huller yielded particularly good results, with characteristics equivalent to those of traditionally whitened fonio: the grain is correctly de-germed, swells up properly and has a soft consistency prized by consumers (Fliedel *et al.,* 2004).

In economic terms, the cost of whitening with an electric GMBF huller equipped with a winnowing channel was evaluated in 2004 with the following hypotheses:
– Investment: huller + winnowing channel = 1,500,000 FCFA (approximately €2,300).
– Equipment service life: five years.
– Depreciation over service life.

– Actual use: 1,000 h/year.
– Continuous actual throughput: 100 kg/h.
– Quantity of processed fonio: 100 t.
– Personnel required: 1 miller (1,500 FCFA/day).
– Electricity cost: 150 FCFA/kWh.

The cost of using the machine tested in Mali was evaluated at 17 FCFA/kg of fonio. Energy consumption represents 36 % of total cost; maintenance and spare parts 31 %; depreciation 18 %; and personnel 12 %.

This cost rises to 24 FCFA/kg if use is limited to 40 t per year. By way of comparison, the cost of traditional manual whitening, carried out by the women in Bamako, is 20 to 25 FCFA/kg.

GMBF fonio hullers are currently manufactured, especially in Mali, by various local equipment manufacturers. These manufacturers need high-performance machines-tools (lathes, etc.) to carry out highly precise machining work on the constituent parts of the huller. Due to the very small size of the fonio grain, the hulling chamber must be perfectly calibrated to prevent any product leaks during hulling and whitening. To make the machines, these manufacturers must select wear-resistant materials, and achieve a high quality process to ensure that these machines comply with the manufacturing designs.

The manufacturing specifications for the various equipment (hullers, winnowing channels and rotary screens) were published by the publisher "L'Harmattan" (Paris), and can be freely used by any interested equipment manufacturers (Marouzé *et al.*, 2005a, 2005b, 2005c).

Roller huller

Today, hulled fonio sometimes referred to as "pre-hulled" fonio is sold on local markets, and certain processing units produce hulled fonio intended for export. To carry out hulling only on paddy fonio, they may consider using a rubber roller huller, as with rice.

This kind of huller comprises two touching rubber rollers, turning in opposite directions at different speeds (figure 6.14). The grains are hulled by "shearing" as the grains pass between the two rollers. The mix of hulled grains and hulls drops into the sorting channel where the hulls are drawn in by a fan, while the hulled fonio is collected by gravity on the side of the machine.

These machines, which are marketed for rice, could be adapted to fonio by improving the feed system to adjust to the small grain size of fonio, and by correctly adjusting the hull suction flow, as with the winnowing channel described above.

With this sort of equipment, we should be able to obtain high throughputs with a good hulling yield of around 80%. If the rate of hulled grains is insufficient, it is always possible to perform several runs in succession. Roller hullers have the advantage of enabling "gentle" hulling of the cereal, generating little breakage. The main problem involves wear of the rubber rollers, since crude fonio is a highly abrasive product. In every case, the raw material must be thoroughly pre-cleaned to eliminate the impurities, and in particular the grit, which always causes premature wear of the machines.

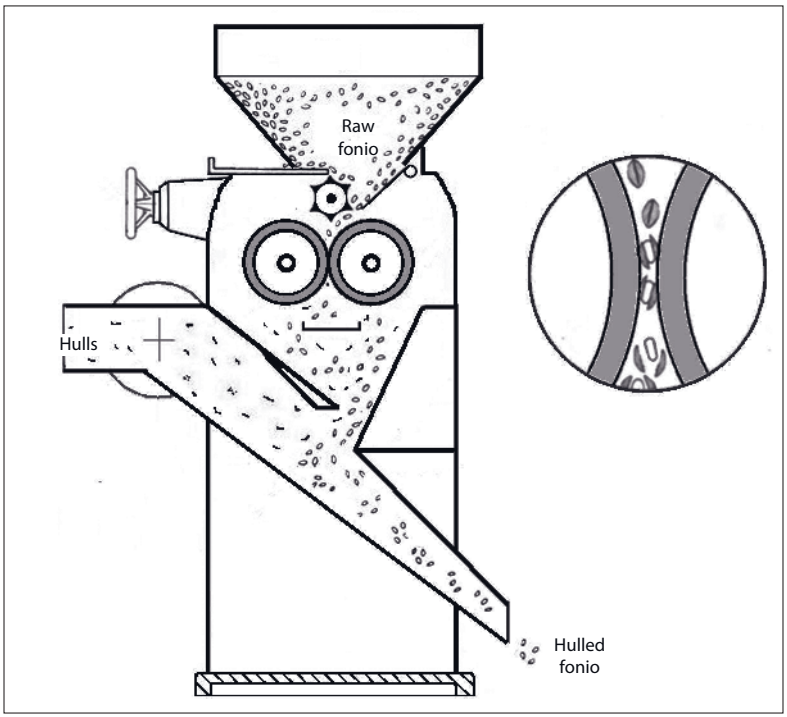


Figure 6.14. Schematic of the roller huller (Cruz *et al.,* 2009).

7. Developing new products

Fonio processed on an artisanal basis, and sold in bulk in the urban markets is most often hulled fonio or whitened fonio, which housewives will then finish preparing as a basic dish.

Today, however, many small companies or women's groups are selling pre-processed fonio packaged in 500 g or 1 kg plastic sachets. New fonio products available include:
– Precooked fonio (the most common type, sold in Mali, Burkina Faso, and Senegal).
– Whitened fonio (fairly uncommon, sold in Mali, Burkina Faso, Senegal and Guinea).
– Grilled fonio (fairly uncommon, primarily sold in Guinea).
– *"Djouka"* fonio (fonio with peanut, primarily sold in Mali).
– Fonio flour (fairly uncommon).
– *"Moni"* and *"dégué"* couscous (rolled products produced from fonio flour, fairly uncommon).
– Parboiled fonio (new product, still uncommon, often reserved for export).

These products are sold above all in district shops or the supermarkets in big cities in West Africa. Precooked fonio is the most commonly manufactured, and is also exported to Europe or the United States to be sold on niche markets.

In 2006, the European Commission funded a fonio project relating to improving the quality and competitiveness of fonio in West Africa. This international project was coordinated by CIRAD and conducted in collaboration with national research institutes in Mali (Institute for Rural Economy) and Guinea (Guinea Agronomic Research Institute), an international centre in Burkina Faso (CIRDES), an international NGO in Senegal (ENDA), an agronomic research centre in Belgium (CRA-W) and a Dutch university (Wageningen University). Favouring a multi-disciplinary approach, the project brought together scientists from various fields: food technology, nutrition, process engineering, mechanisation, social sciences, agronomy, etc. and the research and development actions conducted favoured a participatory approach, involving producers, processors, women's groups and small companies. Besides studying cultivation and production systems (see chapter 3), the project was an opportunity to analyse the technological and nutritional qualities of fonio (see chapter 5) and better characterise new fonio products, such as precooked fonio and

parboiled fonio. This provided the framework for various technical studies relating in particular to precooking, parboiling and drying fonio, and for furthering knowledge of marketing and consumption methods. The results were published in CD-ROM form (Cruz, 2011).

Precooked fonio

Precooked fonio is a whitened fonio which is first steamed, and then dried before packing. Precooked fonio has the advantage of keeping better than plain whitened fonio, and at local level is a good fit for the increasing demand from young urban housewives for ready-to-eat foods.

Manufacturing precooked fonio

The various stages of manufacturing precooked fonio were observed on the premises of small companies in Ségou, Bamako and Ouagadougou.

The utensils used at this level are relatively rudimentary. The couscous cookers used usually comprise two terracotta or aluminium receptacles. The bottom pot, which contains water, has another pot or basin on top of it with a perforated bottom, which is filled with whitened fonio (figure 7.1). These receptacles are joined via a seal made of wet clay or a flour made from néré seeds. The whole apparatus is placed over a wood, coal or gas stove, depending on the circumstances. Stoves range from a simple "3-stone" stove to the more sophisticated gas burner.

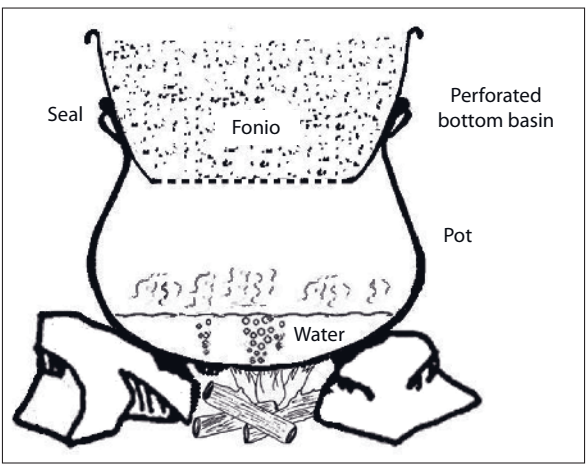


Figure 7.1. Diagram of a traditional couscous cooker over a "3-stone" stove (Cruz *et al.,* 2009).

When the water from the lower pot boils, steam appears in the upper receptacle. The whitened fonio grains, which have been washed and separated from impurities such as grit, are then poured directly into the upper basin. If this basin has large perforation holes, a clean poplin cloth is laid on the bottom to prevent grain leaks. The whole apparatus is then covered with a fine cloth and then a metal lid. Depending on the size of the utensils used, the quantities of wet fonio placed in the upper pot may vary from 10 to 45 kg. After thirty to forty minutes of steaming, the operators consider precooking of the fonio complete. Some of them identify the end of precooking by the pot of grains changing colour, and the appearance of steam on the surface.

The stove is then switched off, and the precooked fonio is emptied into basins using large skimmers or spoons. It is then gently ground to break the lumps, and finally forced through a sieve to break up the last agglomerates.

The wet precooked fonio is then spread in a thin layer onto drying tables to be dried in the open air, or in a "greenhouse" drier, or alternatively onto gas dryer trays. After drying, the precooked fonio is packed into small sealed plastic sachets (500 g and 1 kg) for sale.

Flow diagram of fonio precooking

The fonio precooking flow diagram (figure 7.2), developed during the tests conducted in Mali, is as follows:

Washing and degritting consume nearly 4 l of water per kg of fonio, and 10% of this water is absorbed by the product, which is rehydrated during these operations. On a basic stove, wood consumption is high: more than 20 kg of wood to precook 100 kg of fonio, i.e. an energy quantity of nearly 3,600 kJ per kg of fonio. A gas stove, generally more efficient, uses four to five times less energy, i.e. approximately 800 kJ per kg of fonio.

Parboiled fonio

Parboiling is a very old process generally used for rice, and which consists in hydrothermal treatment of the paddy grains, followed by drying. This technology has the advantage of improving the technological, nutritional and culinary characteristics of the rice.

The idea is to use the same process for paddy fonio, in order to harness the same technological and nutritional advantages. Nonetheless, parboiling has the consequence of colouring the grains, and the rather colourless, very whitened appearance of the grains represents one of the main quality criteria

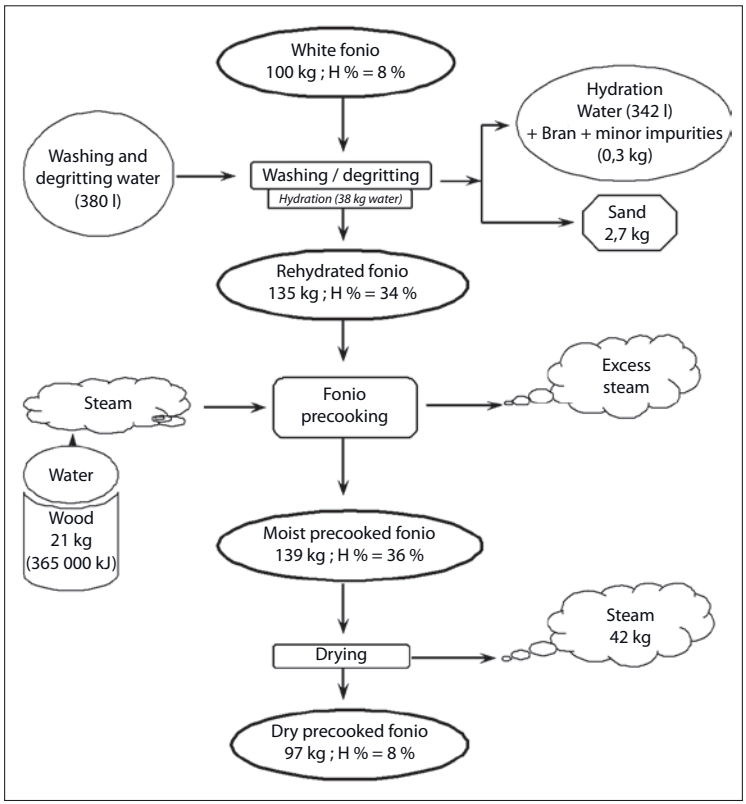


Figure 7.2. Flow diagram of fonio precooking over wood stove (Rivier and Cruz, 2007).

for fonio for regular African consumers. As a result, parboiled fonio is a new product that is likely to be more attractive to new consumers, be they African, European or American. Thanks to the development of post-harvest equipment, and in particular the GMBF huller, certain companies have begun producing processed fonio and are already offering whole parboiled fonio on the European market.

To begin with, knowledge remained highly empirical, and there was no parboiling flow diagram. During the fonio project, CIRAD dedicated part of its research to investigating parboiling fonio and to developing the parboiling flow diagram.

In technical terms, parboiling is a process which consists in precooking pre-rehydrated paddy fonio. This precooking gelatinises the starch, which loses its crystalline structure. After cooling and drying, the kernel of the

grain has a homogeneous and corneous texture. So parboiling improves the technological quality of fonio, by healing split grains, and thereby reducing the breakage rate during hulling. It increases the organoleptic and nutritional qualities, by enriching the kernel with hydrosoluble elements (minerals, vitamins and proteins) initially concentrated in the peripheral layers of the grain.

Studies showed that the water content of fonio after soaking should be 32 to 34% wb (wet base moisture content), to ensure sufficient gelatinisation of starch during subsequent steam treatment. In the laboratory, this water content was obtained by soaking dry grains (9% wb) in water kept at 40 °C for approximately two hours. On-site tests conducted in Mali were able to achieve this water content by soaking the paddy fonio for three hours in water heated to 65 °C, and then cooled naturally, or by soaking for fifteen hours in water at 25 °C. This overnight soak is more practical for small companies to employ, though it can significantly affect the grain colour, making them less white.

When the fonio has been rehydrated by soaking to 32% moisture content, it can then be transferred to a parboiler to be steamed for approximately thirty minutes. The parboilers may be the same utensils used for precooking, or even the metal drums conventionally employed for parboiling rice (figure 7.3).

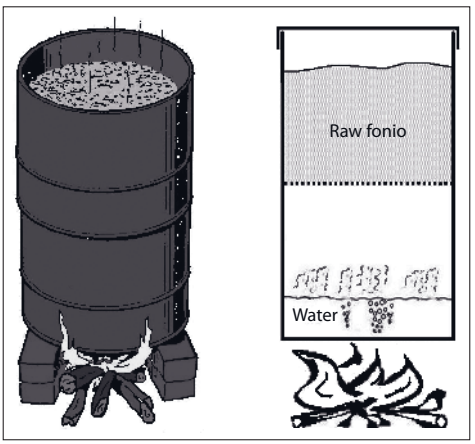


Figure 7.3. Principle of parboiling paddy fonio in a drum (Cruz *et al.,* 2009).

Paddy fonio parboiling tests (figure 7.4) were carried out in Mali under the following conditions:
– Raw material: 30 kg of "Tama" variety fonio.
– Soaking paddy fonio: three hours in water heated to 65 °C, then cooled naturally (at the end of soaking, the water temperature is just 46 °C).

– Fonio drip-dried and then placed inside the parboiler.
– Heating of the parboiler: steam appears on the surface of the product after one hour and ten minutes of parboiling. Parboiling was then continued for twenty minutes.

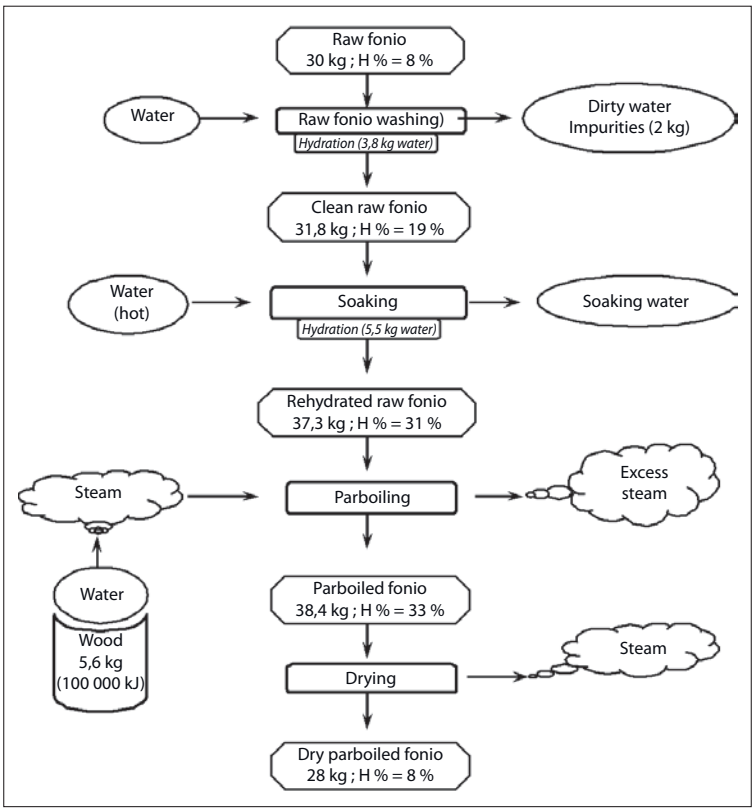


Figure 7.4. Flow diagram of the fonio parboiling operation (Cruz *et al.,* 2009).

Analyses of fonio samples taken before and after confirm that parboiling improves the technological quality and decreases breakage, as table 7.1 shows.

Table 7.1. Improving fonio technological quality by parboiling.

Product	Hulling yield (%)	Whitening yield (%)	Processing yield (%)	Breakage rate (%)
Paddy fonio	82.0	91.0	74.6	0.64
Parboiled paddy fonio	83.0	93.0	77.2	0.03

Source: CIRAD

Excessively long soaking can affect the grain colour. After parboiling, the kernel of the parboiled fonio grain is golden brown to brown in colour, which becomes particularly pronounced the longer parboiling is continued. Nonetheless, on cooking, the fonio grain will tend to gradually become lighter, even if not quite returning to its original white colour. Parboiled fonio grains are less sticky, and often swell better on cooking.

Research should be continued, to enhance knowledge of parboiling fonio, and develop parboiling equipment suited to the requirements of small companies and women's groups, while taking energy and environmental constraints more into account.

8. Improving processed fonio drying techniques

Fonio grains must be dried to a safe moisture content of around 11%, or even 10% for the processed product, in order to keep well. Traditional drying of processed fonio (washed whitened fonio, precooked fonio, parboiled fonio, etc.) often involves simply drying in direct sunlight, with the grains spread on mats or platforms covered with a cloth or plastic sheet. As they dry, the grains may therefore be contaminated by various impurities (dust, bird droppings), which devalue the product considerably.

Some initiatives to improve drying

"Shell" dryer

This dryer, designed by GERES ("*Groupe énergies renouvelables et environnement*") based in Marseille, and GRET ("*Groupe de recherche et d'échanges technologiques*") based in Paris, has been distributed in Burkina Faso since the 1980s for drying fruits, vegetables and cereal products (Rozis, 1995). It comprises a circular chamber with a tapered bottom resting on three legs (figure 8.1). The chamber, the diameter of which can reach 110 cm on larger models, is equipped with circular grates, and has drilled aeration holes to allow air circulation by natural convection. The body of the dryer is covered with a tapered roof which can be enclosed if it rains. The whole dryer looks like a bivalve shell, hence its name.

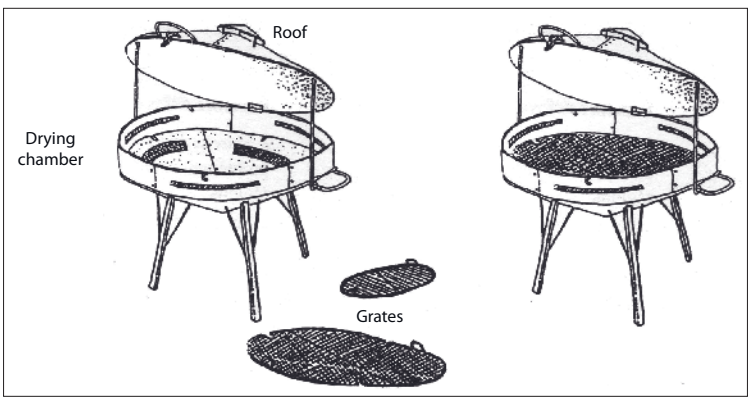


Figure 8.1. Shell dryer (according to Rozis, 1995).

Drying tests were conducted in 2000 on 5 kg samples of washed whitened fonio or precooked fonio placed on just one grate. In the dry season, it took nearly 24 hours to dry the product sufficiently (< 10%). In the wet season, the degree of dryness (of washed whitened fonio or precooked fonio) remained distinctly insufficient even after 72 hours of drying. Condensation on the upper dome of the dryer appeared with the cooler night-time temperatures, causing water droplets to fall onto the product as well as incipient alteration. In cloudy, very wet weather, the shell dryer cannot ensure that the product dries quickly enough. It is often limited to domestic use, as its excessively low capacity makes it inappropriate for making large, commercial quantities of fonio.

"Ceas-Atesta" dryer

The "Ceas-Atesta" dryer was designed in the early 1990s in Burkina Faso, by CEAS ("*Centre écologique Albert Schweitzer*"), and manufactured by Atesta ("*Atelier énergie solaire et technologies appropriées*") in Ouagadougou. It is a natural convection gas dryer designed initially to dry fruits (mangoes, etc.) and vegetables (onions, gumbo, etc.), but which is sometimes used by cereal processors (fonio, rolled products such as "couscous", etc.).

The Ceas-Atesta dryer comprises a brick or masonry base supporting two adjacent metal cells, equipped with drying trays (figure 8.2). The assembly is covered with a roof equipped with a chimney for removing exhaust air.

Under each of the cells, the base comprises a compartment equipped with a gas train. An opening at the rear takes in combustion air, and a flap on the front enables ignition and burner control. Each of the drying cells can take ten superimposed trays, of 0.7 m^2, fitted on slides. The dryer is front loaded in batches. The Atesta dryer can be manufactured locally, at a cost of around 1 million FCFA (approximately €1,500).

Fonio drying tests were conducted in Mali during the rainy season, where each tray was filled with 2.5 to 3 kg of wet product. Results showed that the water content of precooked fonio could be reduced from 30% to less than 10% in approximately three hours. However the trays need to be changed every hour, to ensure more even drying.

Natural convection does not make effective use of the drying capacity of hot air. The dryer's efficiency is relatively mediocre, leading to high gas consumption, which generates a drying cost of 50 to 55 FCFA (€0.07 to €0.08) per kilo of dry fonio. The energy cost represents an excessive expense for certain women processors, who have abandoned this dryer, or only use it at the end of drying.

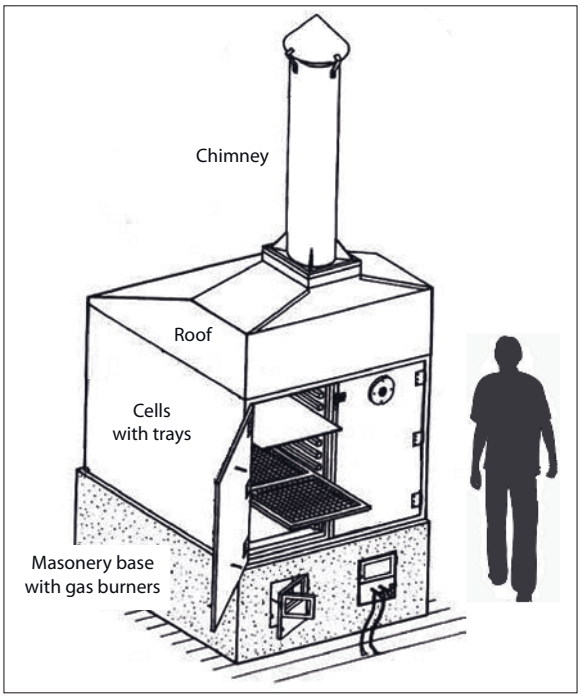


Figure 8.2. Atesta gas dryer (according to CEAS doc.).

To remove the constraint of frequently handling the trays, a variant was developed in Mali called the "Fac 2000 dryer". The hot air is distributed at several levels in the drying chamber to supposedly enable rapid, uniform drying of the product without having to change the trays. Yet this principle does not ensure proper saturation of the exhaust air, and leads to excessive energy consumption due to poor thermal efficiency.

Dryers developed under the fonio project

"Cross-flow" dryer

The "cross-flow" dryer called "CSec-T" was developed by CIRAD for drying granular products (fonio, couscous). It comprises three cells, each containing four superimposed trays, and equipped with a hot air generator with gas burner (8 kW) and a fan driven by an electric motor (figure 8.3).

The structure is made from plywood. Wet fonio is spread onto each tray, on a net cloth which is able to contain the product and collect it once dry.

The hot air flows through the three cells into a duct under the trays, and then passes through the various trays from bottom to top, thereby drying the grains (figure 8.4).

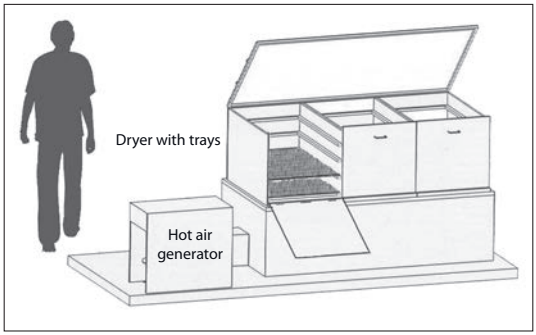


Figure 8.3. Drawing of the "CSec-T" cross-flow dryer (according to J. Brouat, CIRAD).

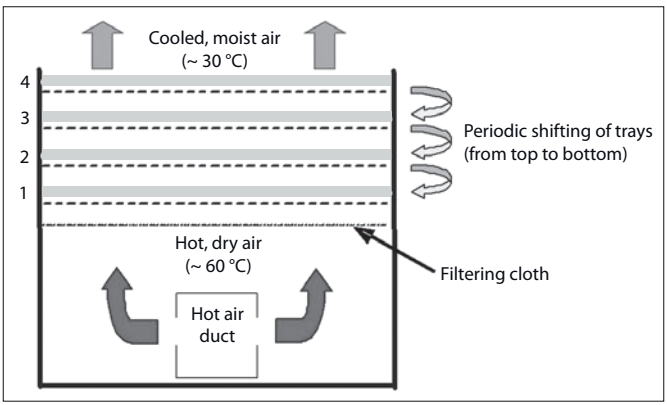


Figure 8.4. Principle of cross-flow dryer with trays (Cruz *et al.* 2008).

The air speeds hitting the trays must be limited to between 0.2 and 0.3 m/s, to prevent the grains from being carried away. When the product on the lower tray is dry, it is removed, and the upper trays are moved down one level; the upper tray is then reloaded with wet product. This practice makes sure that the drying air is saturated, thereby improving the thermal efficiency of the dryer (Rivier *et al.* 2016).

The cross-flow dryer was installed in several small companies or EIG in Burkina Faso, Mali and Senegal, and tested jointly by employees at the companies, the EIG and local research teams (Cruz, 2016). In Mali, drying

tests were conducted on precooked fonio in the dry season and wet season. The main results obtained during the rainy season (July and August) are set out in table 8.1 below:

Table 8.1. Performance levels of the cross-flow dryer (CSec-T).

Mass of wet precooked fonio	98 kg
Initial moisture content of precooked fonio (wb)	31.1%
Mass of dry precooked fonio	72.8 kg
Moisture content of dried precooked fonio	7.3%
Total drying time	4 h

Source: CIRAD

According to the SME and EIG managers who used it, this dryer has two advantages:
– Good drying capacity. A drying cycle can dry around one hundred kilos in four hours, i.e. 200 to 300 kg of precooked fonio per day, running several cycles.
– Gas consumption lower than for other gas dryers (Atesta, Fac 2000, etc.).

Energy consumption is reduced because the evaporating capacity of the drying air is maximised as it flows across the four trays, and emerges practically saturated with water.

As with many grated dryers, the main difficulty of the cross-flow dryer lies in the need to frequently move the drying trays, with changes every thirty minutes, to achieve efficient drying.

The dryer can easily be made by local companies, since the necessary manufacturing materials are wood for the drying cells, and metal sheeting for the hot air circuit. The cost of manufacturing a CSec-T dryer is around 1 million FCFA (approximately €1,500), and its cost of use is evaluated at 35 FCFA (€0.05) per kilo of dried product (Cruz *et al.,* 2008).

In future, the addition of a solar collector as a hot air generator, upstream of the device, could be considered, while retaining the gas burner as an auxiliary heat source for periods of low sunshine, or to take over drying at the end of the day.

Using a collector with a specific capacity of 40 $m^3/h.m^2$, a surface area of 30 m^2 would be required to provide the dryer's feed flow, which is estimated at 1,200 m^3/h. This sort of space is often available in the processing workshops. Nonetheless, with a flat collector it is difficult to achieve ambient temperatures of more than 20 °C or a hot air temperature above 60 °C, which reduces the dryer's performance accordingly.

"Greenhouse" dryer

The "greenhouse" dryer called "CSec-S" developed by CIRAD is an alternative to drying directly in the sun.

The greenhouse dryer comprises a galvanised tube structure topped with a plastic film. The structure rests on a concrete slab and masonry gables or better, acrylic glass (PMMA) gables. The front gable has a door opening, and two windows equipped with mosquito netting (figure 8.5.).

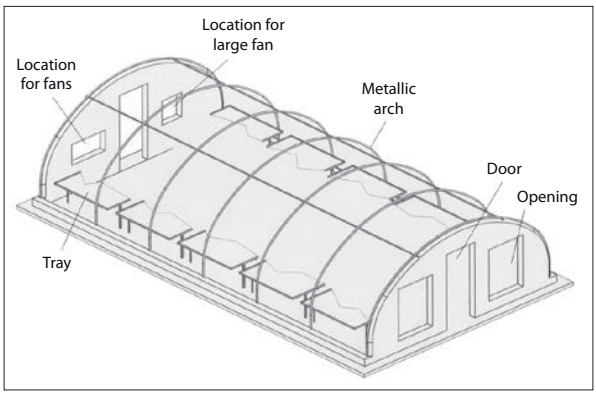


Figure 8.5. Greenhouse dryer structure (according to J. Brouat, CIRAD).

The rear gable of the dryer is equipped with one or two axial fans, which can run continuously to renew the air in the dryer, and another higher-capacity fan, which must be activated to enable the operators to enter the dryer during the day to mix the product.

The greenhouse dryer is equipped with tables or trays covered with mats and cloth sheets on which the wet fonio is spread in thin layers. 300 to 400 kg of precooked fonio can be dried with this dryer model (Cruz, 2014).

In 2006, an initial model of the greenhouse dryer was installed in Bamako (Mali) on the premises of a company producing precooked fonio. In 2015, a newer dryer was installed in Kédougou (Senegal). The main characteristics of the experimental dryer are given in table 8.2 below:

Table 8.2. Main characteristics of the greenhouse dryer (CSec-S).

Length	12 – 14 m
Width	6.4 - 6.5 m
Total surface area of trays	35 - 45 m^2
Load per m^2	9 to 10 kg/m^2

Source: CIRAD

The greenhouse dryer (CSec-S) tests were conducted jointly by company employees and local research teams. The main results for drying of precooked fonio carried out during the rainy season (July and August) are set out in table 8.3 below:

Table 8.3. Performance levels of the greenhouse dryer (CSec-S).

Mass of wet precooked fonio	400 kg
Initial moisture content of fonio (wb)	32.5%
Mass of dry precooked fonio	294.7 kg
Moisture content of dried fonio (wb)	8.4%
Total drying time	24 h

Source: CIRAD

Depending on the users, the main advantages of the greenhouse dryer are as follows:
– The product is protected from the weather, and good quality drying is achieved whatever the season (dry or wet).
– The product is protected from depredation (birds or rodents), and from external contamination (dust, sand).
– There is less handling: the fonio can remain in the dryer overnight, even when it is raining.
– Drying is relatively quick (less than 24 h), and the drying cycle is compatible with the company's work structure.
– Energy consumption is low, amounting only to the operating requirements of the fans.

The total investment for setting up a greenhouse dryer is relatively high, potentially reaching 3.5 to 4 million FCFA (approximately €5,300 to €6,000), but its cost of use is less than other mechanised dryers, at just approximately 25 FCFA (€0.04) per kilo of dry fonio.

Cross-flow and greenhouse dryers proved satisfactory to the users, both for their daily capacity and their quality of drying. Being able to produce quality fonio all year round represents a very big advantage for them (Cruz, 2016). Furthermore, this equipment is versatile, and can be used on other granular food products (couscous and other rolled products, grits, etc.).

9. Trade

For a very long time, fonio production was primarily intended for self-consumption, to satisfy the requirements of the producers during the lean season. A small proportion was sold in bulk form on local markets. Yet processing difficulties led many producers to abandon this crop. Then some women's groups and private companies started selling processed fonio, and in particular precooked fonio, packed in sachets, in small stores or supermarkets in the big cities. This new outlet gave fonio an image makeover; no longer is it considered the "cereal of the poor", but is a food much prized by urban consumers. With the recent development of mechanisation of hulling and improved drying techniques, the manufacture of precooked fonio can now be spread throughout the year, and volumes sold in local establishments and in the export sector are rising.

The fonio trade in Guinea

Fonio, the main cereal sold after rice

The fonio trade in Guinea has been studied in particular by IRAG as part of the fonio post-harvest technology improvement project. As a reminder, while fonio is cultivated throughout the country, it is produced in the natural regions of Middle Guinea (Fouta-Djalon) and Upper Guinea (from Faranah to Kankan and Siguiri). In these regions, it is the second most sold cereal after rice, as the surveys conducted on Labé, Faranah and Kankan markets show (table 9.1).

Table 9.1. Relative share of cereals sold on certain markets in Guinea.

Products	Labé market	Faranah market	Kankan market
Rice	58%	71%	55%
Fonio	31%	25%	23%
Millet and sorghum	5%	4%	12%
Maize	6%		10%

Source: IRAG

There are also certain markets specifically dedicated to fonio, such as Miti, a small village on the Labé road between Dalaba and Pita.

On the various weekly markets, fonio is primarily sold in the form of hulled fonio. Selling in the form of paddy fonio is less common, and whitened fonio is sold only occasionally.

Industry operators

The main industry operators are identified in the flow diagram below (figure 9.1):

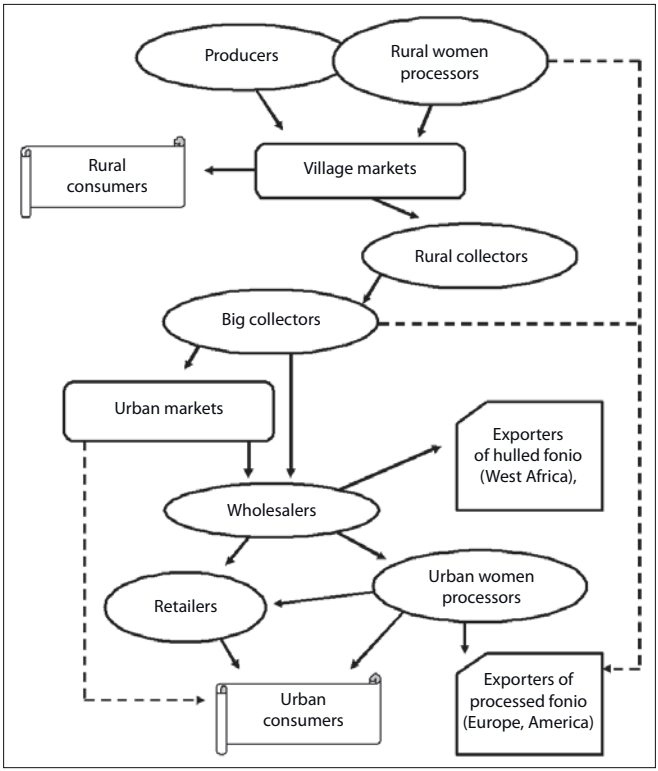


Figure 9.1. Simplified flow diagram of the fonio industry in Guinea.

Rural women processors

The rural women processors, often the wives of fonio producers, carry out hulling themselves by manual grinding, without taking the process as far as perfect whitening. The fonio processed this way, sometimes dubbed "pre-hulled fonio", is then sold on local markets or to collectors.

Collectors

Collectors — who are often also women — are paid by the big collectors or semi-wholesalers to purchase prehulled fonio, and sometimes already whitened fonio, from the various village markets. Most of them also buy up

other foods, such as rice, sorghum, peanuts, etc. Many of these collectors are now equipped with mobile phones to keep informed of market prices in real time. Transactions are rarely made by weight; they are generally based on local measures such as the *saria* in Middle Guinea and *moussa traoré* in Upper Guinea.

Big collectors

It is often at the weekly markets that the big collectors collect the products brought together by the rural collectors, after checking their quality. The fonio collected in this way (prehulled fonio, whitened fonio, etc.) is then packed in 50 to 100 kg sacks, to be sold on to wholesalers in the big cities.

Wholesalers

Wholesalers collect and store various batches to supply the urban markets and the capital Conakry. The cities of Labé, Mamou, Faranah, Kissidougou and Kindia are the main markets where the fonio is collected before supplying the urban centres of Conakry, Kankan and Guéckédou. Wholesalers are organised in associations, and also export their foods to neighbouring countries. Hence some of the fonio from Middle and Upper Guinea is exported north to Senegal and Gambia, and east to Mali or Côte d'Ivoire. In Senegal, it is the big weekly market of Diaobé, situated in Upper Casamance, between Velingara and Kolda, which sells a large proportion of the Guinean fonio traded in Senegal, in the form of prehulled fonio.

Urban women processors

These urban processors are sometimes women who have set up their own SME, or formed associations to purchase bulk prehulled fonio from markets or wholesalers. They process it to make a finished product (whitened fonio, grilled fonio), often packed in plastic sachets and sold to retailers, exporters or directly to consumers.

Retailers

The final link in the local industry, retailers ensure a good trade flow of fonio to urban consumers. Retailers will sometimes repack processed fonio themselves, if they have bought it in bulk from women processors. They pay close attention to quality, in order to cultivate customer loyalty.

Exporters

In recent years, a processed fonio export market to Europe and North America (United States and Canada) has been developing. This new market,

which may have a driving effect on the industry, nonetheless needs to satisfy relatively strict quality requirements (grains well hulled, free from grit, etc.). Today, exporters generally procure from urban women processors, though larger order volumes for export could lead exporters to procure directly from rural women processors, who would then carry out all the fonio processing operations in villages.

Price trends

Prices undergo significant seasonal variations between the major harvesting season in September and October, and the lean season in June, July and August.

Processing and transport costs are two expenses which weigh heavily on the price of fonio.

In 2003, when the average production cost was around 130 to 140 FG/kg (approximately 40 FCFA/kg, i.e. €0.06/kg), prices of various forms of fonio traded in Guinea were as follows:
– Paddy fonio: 250 to 410 FG/kg (i.e. 71 to 117 FCFA/kg, or €0.11 to €0.18/kg).
– Hulled fonio: 700 to 1,200 FG/kg (i.e. 200 to 345 FCFA/kg, or €0.30 to €0.42/kg).
– Whitened fonio: 800 to 1,500 FG/kg (i.e. 230 to 430 FCFA/kg or €0.35 to €0.65/kg).
– Whitened fonio (grilled or ungrilled), packed in sachets: 2,500 FG/kg (i.e. 715 FCFA/kg or €1.1/kg).

Guinean fonio is still sold in a fairly unprocessed form, without much added value. Though it is supplied to many sub-regional markets, it is poorly valued internationally, where the bulk of the products sold on the "organic and fair trade" markets in developed countries comes from neighbouring countries like Mali, Senegal or, further afield, from Burkina Faso. The new potential represented by the recent mechanisation of post-harvest operations should in future make it possible to diversify the supply of high-quality fonio products.

Precooked fonio trade

Precooked fonio is one of the "new fonio products", and the bestselling one in West Africa and the export sector.

A few trailblazing small companies

In the early 1990s, a few small companies, very often family-owned, and women's groups, started to produce precooked fonio in Mali, and then in

Burkina Faso and Senegal. The trailblazing companies included in particular: Ucodal in Bamako, the women's association *Wend Benedo* in Ouagadougou, which sold fonio under the Tomé brand, and the *Koba Club* group in Kédougou. Many of them were not specialised in fonio, but offered a diverse product range based on local cereals or condiments. The preparation and packing operations remained primarily manual, and despite the laboriousness of the work, these trailblazing companies have stood the test of time, and have played an important role in revitalising the fonio industry.

Development of the sector through mechanisation of post-harvest operations

Gradually, some of these small companies became specialised in precooked fonio production, which was packed in sachets to supply local stores and supermarkets, and developed a small-scale export industry. The targets they had in mind were the relatively well-off customers in big cities, and the West African diaspora in certain countries in Europe or North America.

Precooked fonio was a big hit, and demand grew steeply, at both local and export level. To meet this new demand, the companies, quickly coming up against the limits imposed by manual labour, sought the help of the research sector to procure specific equipment that provided high performance in terms of both productivity and quality. The development of hulling, cleaning and drying equipment enabled existing companies to better meet growing demand and favoured the emergence of new small companies. While there were just a few examples during the 1990s, there are now almost fifty small companies producing precooked fonio in West Africa. Many are not yet equipped with machines, and so for hulling, turn to recently established service providers to meet this new demand. Most of the companies are established in the capitals, where the bulk of the market is based, and to a lesser degree, in the cities of major production zones. In Mali, nearly 80% of small companies are based in Bamako, and the rest in Ségou and Kayes. In Burkina Faso, the companies are based primarily in Ouagadougou and Bobo Dioulasso, while in Senegal, they are located in Dakar, Kédougou or Kolda.

In Mali, certain women processors from Bamako purchase their raw material directly from the producers or at the big markets in the production zones (Bougouni, San), but most of them procure from the "national market" in Bamako, where wholesalers sell fonio imported from Fouta-Djalon or Upper Guinea. The quality of Guinean fonio remains highly rated. The quantities available are always high, sometimes representing tens of tonnes of fonio of various qualities and at different prices, depending on the level of hulling and cleanliness of the batches.

Local precooked fonio trade

The precooked fonio market has seen rapid growth since the early 1990s. Today, more than twenty different brands are available in Ouagadougou, Bamako and Dakar. Precooked fonio is usually packed in 1 kg, or sometimes 500 g, heat-sealed polyethylene sachets (photo 9.1). Thanks to promotional campaigns, but most of all to the vitality of local women processors, it is now available in most stores or supermarkets in Bamako, Ouagadougou or Dakar, and is familiar to most customers, although not all purchase it. A survey conducted in a big supermarket in Bamako in 2007 showed that around one hundred kilograms of precooked fonio was on sale, divided into eighty 1-kg sachets of two different brands, and forty 500-g sachets of the same brand.

Photo 9.1. Sachet of precooked fonio (© J.F. Cruz).

The prices of precooked fonio in this type of packaging are relatively stable throughout the year. In Bamako, they vary between 850 FCFA (€1.30) and 1,200 FCFA (€1.83), though the price more frequently observed is 1,000 FCFA (€1.52) per 1-kg sachet, and 500 FCFA (€0.76) per 500-g sachet. These same prices were also observed in Ouagadougou. They may vary slightly, but primarily this is down to the brand and point of sale. Of the price paid by the precooked fonio purchaser, 30% goes to producers, 20% to traders and 50% to women processors, who have the heaviest workload and the highest costs.

Customers are often very satisfied with the quality of precooked fonio in this sort of packaging, although in rare cases, some complain of the presence of grit, or a bad smell from fonio of one brand or another. Criticism most often relates to the poor quality of packaging, which is not solid enough or isn't well sealed.

Precooked fonio purchasers are generally the better-off city dwellers, who are more educated than purchasers of traditional products (hulled fonio and whitened fonio sold in bulk on the markets). Individual purchases are of relatively small quantities, i.e. 1 to 2 kg, but when requirements are greater, in particular during festive periods or ceremonies, many customers revert to the traditional products sold more cheaply. So precooked fonio is only replacing traditional products to a very slight extent.

Export sale of precooked fonio

For a long time, export sales of fonio remained informal, and its scale hard to assess. Sometimes it involved just a few sacks of whitened fonio placed in a container filled with various African products to be exported. During the 1990s, only two brands, including Ucodal from Mali, introduced precooked fonio to the French market, in plastic sachets. Target customers primarily comprised consumers originating from Sahelian countries such as Mali, but also Burkina Faso or Senegal. The overall volume could vary from a few tonnes to tens of tonnes.

Gradually, demand increased, though the supply from local women processors remained limited because of their limited production capacity. The development by various fonio projects of high-performance hulling machines and dryers eliminated some of the main bottlenecks in the industry. In the early 2000s, existing companies were able to procure machines to better satisfy demand. Similarly, the mechanisation of hulling boosted the emergence of new precooked fonio production companies, some of which became exporters. In 2007, the production of new fonio products in Mali – primarily precooked fonio – was assessed at more than 250 t, of which at least two thirds was aimed at the export sector. There were plans to increase production, or even double it, by 2009. However, these quantities represent just 5 to 10% of the fonio sold locally, and barely 1 to 2% of Mali's national production, estimated at nearly 30,000 t of paddy fonio.

In France, Racines, a Montpellier based company, sells a multitude of food products of tropical origin. In the early 2000s, thanks to close collaboration with research laboratories such as CIRAD, it was one of the main companies to import precooked fonio from Mali, to repackage it and distribute it at its many points of sale throughout France. Today, this company alone sells tens of tonnes of precooked fonio per year.

Later, in 2004, the association Le Damier helped set up an organisation of fonio producers in the Kéniéba area in the southern part of the Kayes region in western Mali. In 2006, this organisation, dubbed Benkouto, which means "concord" in the Malinké language, represented hundreds of producers from nine villages with the objective of developing an organic and fair trade fonio industry. Thanks to financial support from the French regions Nord-Pas-de-Calais and Île-de-France, and to the commitment of French cooperative company Éthiquable, which is highly renowned in the field of fair trade, local production of precooked fonio was launched. Hence, raw fonio is threshed and then hulled in the villages, which to this end were equipped with threshers and GMBF hullers. Hulled fonio is then transported to the regional capital, Kayes, where it is whitened, precooked and repackaged in cardboard boxes by a small company called "Le grenier du paysan", the producers of which are also shareholders. Production involves a few dozen tonnes, half of which is exported and sold in France by the brand Éthiquable, under the trade name Fonio du Mali, and with the Max Havelaar Fairtrade label.

At the same time, Gaia, a company based in the Tarn Department in southern France specialised in selling organic food products (cakes, biscuits), set up an African subsidiary called Gaia Bio Solidaire, to better promote fonio. After an unsuccessful initial trial run in the Koussanar region of Senegal, Gaia Bio Solidaire teamed up with producers in north-west Burkina Faso. It built a processing unit in Nouna, capital of Kossi province, to produce parboiled whole or semi-whole fonio, marketed in France as an "organic agriculture" certified product. Given the very dark colour of whole parboiled fonio, it is primarily marketed to European customers. Surveys conducted in Montpellier showed that European consumers opted for dark coloured parboiled whole fonio as much as light coloured precooked fonio, whereas African consumers generally consider white-coloured fonio to be one of the main quality criteria of this cereal.

In 2010, Racines, Éthiquable and Gaia were the main brands distributing fonio in France (see colour photo album). Certain other brands also sell it, but this is either parboiled whole fonio or semi-whole fonio, produced by Gaia Bio Solidaire and repackaged by the brands Celnat, Moulin des moines, or France Aglut; or precooked fonio produced by women's groups and marketed by NGOs during temporary fair trade operations. This was the case, for example, with precooked fonio marketed in 2010 by Artisans du monde in France's Rhône-Alpes region, working together with the NGO Afrique Verte Burkina.

10. Consumption

Consumption habits

Fonio has been consumed in West Africa for hundreds of years. In the 14th Century, Ibn Battûta reported that in these lands, couscous was prepared with fonio. In 1830, explorer René Caillé specified that fonio was one of the main foods of the inhabitants of Fouta-Djalon, which was prepared as a gruel seasoned with herbs and gumbo, or in the form of *tô*. Fonio is still highly prized by the local populations and Europeans who live in these regions. In 1909, botanist Auguste Chevalier reiterated that fonio was a near-exclusive staple of the diet of the inhabitants of the high plateaux of Fouta-Djalon throughout the year. Certain travellers spoke enthusiastically and frequently of fonio. In 1929, Émile Perrot, a botanist at the Paris pharmacological faculty, on assignment to Guinea, said that fonio had an exquisite taste. Yet there were sometimes opinions to the contrary. In 1937, Henri Ploughinget quoted the words of a dignitary from Mamou: "*Fonyo* is nice to eat in the spring and during the rains. But when the white winds of November have set in, it is the time for rice. Maize, millet and *fonyo* are put aside for rice; a handful of which is worth more than a big gourd full of *fonyo*, which is now put on the sidelines."

In 1955, agronomist R. Portères reiterated that "Europeans employ fonio for everything from stews to pastries; as a main dish, they consume it as couscous with shell fish (prawns, crayfish or langoustines), or sometimes fish." Furthermore, "couscous with butter or milk sauce is prized by Europeans as baby food. It is recommended for convalescent and sick patients, as well as people with stomach and intestinal fatigue." He noted that below the 12th parallel — situated 60 to 70 km below the line through Ouagadougou (Burkina Faso), Bamako (Mali), and Koundara (Guinea) — fonio was: "a staple cereal as much as any other." North of the 12th parallel, there were only "early and very early varieties, used only as famine and food shortage supplements."

Guinea is located almost entirely south of the 12th parallel, and in the major production zone of Fouta-Djalon, fonio is consumed practically every day as the main meal by most of the rural population. It is indeed the staple food for the often large families who consume their own harvests, as in most villages worldwide. Very often, fonio producers set aside more than 80% of their reserves for self-consumption, keep 15% for seeds, and sell less than 5%. Only poor harvests or difficulties inherent in its preparation (hulling) sometimes limit consumption.

In the cities, consumption is lower, though certain households consume it at least once a week, and in particular families originating from producer regions like Middle or Upper Guinea. Fonio is often considered an ordinary dish, commonly consumed as *foyo* fonio (couscous).

Fonio: a gourmet, tasty and digestible cereal

While fonio is considered to be an ordinary dish, the fact remains that in cities, the difficulties in its preparation – or, in the case of precooked fonio sold in special packaging, its cost – often limit its use to big occasions. Many Bamako housewives consider fonio a luxury product (Fogny-Fanou *et al.,* 2009). In Bamako, Ouagadougou, Dakar or even Conakry, the vast majority of consumers prepare it only occasionally, in particular during Ramadan or harvest time when relatives still living in the villages send them some (Konkobo-Yaméogo *et al.,* 2004). Reputedly the most delicious cereal available, its fine texture and taste make it a choice dish, always served to mark festive periods, important ceremonies or for receiving important guests. A popular proverb says that "fonio never brings shame to the cook." Aside from the usual meals served for lunch or dinner, it can also be offered as a snack, or gourmet dish, to favoured guests. Highly digestible, it is traditionally recommended for baby food, pregnant or breast-feeding women, the elderly and people suffering from obesity.

Fonio consumption outside the home

Consumption outside the home, too often concealed, is now a big phenomenon in many West African cities. It contributes to a diversification of diet, which is a powerful trend in changing eating habits. Through lack of time (work days without breaks) and decent means of transport, many employees, civil servants, merchants, students, schoolchildren, etc. do not have lunch at home, which is often a long way from their place of activity; instead, they eat in one of the many canteens, cafeterias, small restaurants or stand-up eateries which have been established in most big cities. For all social classes, the catering sector is also a way to escape the constraints of family meals, and to treat oneself, perhaps selfishly but always in a nice way, to a "new" dish rarely available at home, because of possible social, cultural or financial pressures. Above all, the possibilities for eating out, often diverse, have the merit of supplementing nutritional intake, which at home generally has little variation, in particular for children of modest families.

In the small restaurants of Ouagadougou or Bamako, cereal-based dishes are the most consumed, and generally rice with sauce is the most popular. But in Bamako, rice is immediately followed by fonio, prepared as *foyo* with

tomato sauce, or as *djouka*, while millet and sorghums, traditional staple foods commonly consumed at home, are less prized. In 1998, the Malian nutritionist Mohamed Ag Bendesh specified that "the catering sector specialises in products rarely consumed at home, such as fonio, beans, drinks, fried products, fruits and vegetables." He also reiterated that "fonio is not a cereal that is part of the usual home diet, but is very often eaten outside the home in "base and sauce" purchased dishes, in particular in the form of *djouka*, or fonio couscous with ground peanut." Surveys conducted in Bamako as part of the fonio post-harvest technology improvement project in the early 2000s showed that fonio-based dishes were well-known to consumers, and that *djouka* was mainly consumed in the morning or the mid-morning during a break, before lunch. For lunch, *foyo* and fonio with tomato sauce are more popular, whereas fonio gruel is mainly reserved for the evening meal.

In Guinea, in small inland cities such as Mamou, restaurants rarely prepare fonio, as it is a dish frequently consumed at home. Only a few street vendors sometimes offer fonio to travellers passing through the bus stations. Yet in Conakry, many customers, and in particular single young men, go to restaurants and cafeterias to eat fonio, especially at lunch. Sometimes consumers order fonio not just to feed themselves, but simply to satisfy a "hankering for fonio".

In the big West African cities, certain restaurants offer more elaborate and more expensive dishes, with fonio accompanied by fish or meat, thus offering better-off customers the satisfaction of eating a typically African dish rich in taste and symbolic quality. Caterers do nonetheless face some difficulties in selling fonio-based dishes, because of the constraints involved in preparing it. The availability of precooked fonio sold in sachets can resolve this problem, but then cost becomes a major constraint, except for the biggest restaurants where dishes can be sold at higher prices. Fonio, a staple food for many rural populations, is becoming a luxury food, which must be of irreproachable quality, and completely free from grit and impurities.

Fonio quality criteria

Whether the purchase involves whitened or precooked fonio, in bulk or in sachets, or the choice of fonio-based dishes, the cleanliness of the point of sale and the product remains the quality criterion deemed essential by consumers. For the point of sale, they take into account the hygiene of the premises and the presentation of the vendor, since they are aware that the lack of official inspection of the food catering sector can potentially pose a health risk. The cleanliness of the product is first judged by a noticeable lack of impurities (foreign seeds, plant debris) or incorrectly hulled grains. Yet visual observation

alone does not confirm for certain whether a product is contaminated by grit, which is the same size as the fonio grains. So housewives or customers rely on the reputation of the trader or caterer, or take into account the region of origin of the product, if it can be determined (Dury *et al.*, 2007). In Mali, fonio from Bougouni is sometimes favoured, while in Guinea, in Fouta-Djalon, there is a preference for mountain fonio, cultivated on gravelly soils, because it is free from grit, unlike plain fonio. Furthermore, it is very white, easy to prepare, and completely suitable for consumers' tastes.

The second major criterion is colour. The colour of the grains, of course closely associated with the level of hulling and whitening, has a direct impact on consumer purchase prices (Dury and Meuriot, 2011). As with rice, African consumers most often seek a very white fonio. In Guinea, where there is great diversity of ecotypes, consumers appreciate the varieties Siragué and Konso, for example, which, after hulling and whitening, provide grains of a fine white colour. Elsewhere too, fonio is naturally associated with whiteness: in Dogon country in Mali, the late September period is referred to as follows: "Which is whiter, fonio or the moon?" Precooked fonio sold in plastic sachets is somewhat beige due to being steamed. Urban consumers are used to this, and therefore more sensitive to whether there are black grains (foreign seeds) in the packet. For new French consumers discovering fonio for the first time, whiteness does not seem to be the number one quality criterion. According to surveys conducted in Montpellier, some actually find very brown-coloured whole fonio more appealing, as it looks more natural.

Grain size is mentioned only rarely as a real quality criterion, and it would be a conceit to want to make it bigger. As a Bambara proverb says: "Only the grain of fonio remains tiny."

In any case, for African or European consumers, or others, the most important quality criterion of a fonio dish is the complete absence of grit. There is nothing more unpleasant than a grain of sand crunching between the teeth during the meal. Suppliers of fonio packed in sachets, aimed at the urban and export markets, must make sure to sell fonio free from grit, unless they want consumers to make a long-term association between fonio and grit (as lentils used to be associated with pebbles).

Preparation methods and recipes

African cuisine is sometimes considered different from other cuisines by virtue of the ingredients used (cereals, roots or tubers, meats and fish, spices, etc.), and the particular way that they are cooked. Yet like many other world cuisines, everyday dishes often consist of a staple food and a side dish (or

sauce). In Guinea, Mali, Burkina Faso, Senegal or elsewhere in West Africa, fonio forms the basis for a host of recipes which are prized in terms of cooking and nutrition. It is usually consumed in the form of couscous *(foyo)*, or light or thick gruels *(dégu, moni,* tô*)*, though there are many other possible preparations (cooked in fat, in salads, cakes, fritters, etc.).

In 1929, in his report on his assignment to Guinea, Émile Perrot stated: "This cereal comes in three forms: as raw seeds; hulled seeds, through gentle soaking; and as whitened seeds, through washing in water, followed by drying. It is consumed boiled, with or without gentle pre-grilling, and has an exquisite taste."

In reality, he was describing only one method of cooking fonio, specific to Guinea, whereas fonio is primarily steamed.

Steaming fonio

This method of cooking fonio, the most common throughout West Africa, is the most prized in particular for preparing festive dishes. It uses a couscous cooker, comprising a lower pot containing water, and an upper basin, with a perforated bottom, which is filled with whitened fonio still wet after washing. The two receptacles, made from terracotta or aluminium, are joined by a seal to prevent steam leaking. The first steaming can last ten to fifteen minutes. The fonio is then emptied from the couscous cooker into another receptacle, and broken up, stirred and sprinkled sparingly with water. Butter or a plant ingredient (gumbo, ground baobab leaves) may also be added, acting as a sticky binder, making it easier to swallow. The fonio is then put back into the couscous cooker for its second and third steaming, to obtain a soft textured, well-cooked fonio.

Boiling fonio

This method of cooking fonio seems to be specific to Guinea, and is used with whitened fonio which has been pre-grilled until dry, in a saucepan. This grilling (roasting), in which a dry heat acts on the starch, gives it greater solubility and digestibility, as well as a very pleasant flavour in the dishes. To prepare *niri fonye,* a famous dish in Guinea, white fonio grains are grilled until they take on a yellow colour. Then they are thrown into a saucepan of water heated to boiling point. Some of the water is removed, to be gradually re-added later, and then it is left to cook on low heat. The dish is accompanied with gumbo sauce and peanut sauce, with pre-crumbled meat or fish.

In Guinea, opinion is very divided on the supposed advantages of boiling over steaming: "speed of cooking", "better swelling on cooking", for some;

"more difficult to get right", "swells less than steamed fonio", for others. Taste tests on dishes made in Guinea with the two cooking methods showed that steaming was generally prized. The dish has a fine appearance, with well-separated grains exhibiting a very white colour, and a pleasantly firm texture. With boiling, dishes are less white, and sometimes less appetising, but they have a "grilled" aroma and flavour which many consumers find very pleasant. Mostly, boiling remains more difficult than steaming, since failing to control the quantities of water and cooking times can quickly result in a badly cooked, pasty and poorly presented dish.

Cooking fonio in fat, a common practice in West Africa, is also actually boiling, since it is carried out in a meat, poultry or fish stock.

Some fonio-based recipes

Steamed dishes

The most commonly prepared steamed dish, in particular for festive periods, is the famous fonio couscous, or *foyo*. It is common in Guinea, Mali and Burkina Faso.

Foyo

Preparation and cooking time:

1 to 1.5 hours

Ingredients (for 5 people):

1 kg fonio, 750 ml to 1 L water, 2 kg meat, 250-300 g fresh tomatoes, 100 g concentrated tomato, 1 kg onions, garlic: to taste, 2 or 3 fresh peppers, vegetables: carrots, cabbage, aubergines, sweet peppers, turnips, courgettes, 1 to 2 stock cubes for flavouring, 250 ml oil, salt, spices (pepper)

Preparation:

– Put the fonio into a receptacle and pour in water (approximately 0.5 L of water per kilo).
– Steam initially for 10 mins.
– After this first steaming, add a little water to the fonio, stirring gently.
– Steam a second time for 5 mins.
– Place the fonio in the couscous cooker. Add pieces of fresh gumbo, cut into thin strips, on top of the fonio.
– Steam a third time, for 15 mins.
– Mix the fonio and gumbo when cooked.

This preparation can be served with various sauces: tomato and meat sauce, tomato and fish sauce, peanut sauce or leaf sauce.

In Mali, *djouka*, or couscous with ground peanut, is a very popular dish.

Djouka

Preparation and cooking time:

1 to 1.5 hours

Ingredients (for 5 people):

1 kg fonio, 2 kg peanuts, 1 L water, 50 ml oil, 1 kg onions, 45 g potash, 500 g fresh gombo, 4 or 5 aubergines, 2 or 3 peppers, garlic, salt, vinegar, spices (pepper, stock cube, etc.)

Preparation:

– Winnow, sort, wash, and dry the peanuts.
– Steam the unskinned grains for 5 mins.
– Grind and sieve to remove seed coats.
– Mix the ground peanut with the potash (40 g) and salt.
– Put the fonio into a receptacle and pour in water (approximately 0.5 L water per kilo).
– Steam initially for 10 mins.
– After this first steam add a little water (300–400 ml) to the fonio, stirring gently.
– Steam a second time for 5 mins.
– Add the ground peanut and spices (black pepper, fresh pepper, etc.).
– Steam a third time for 5 to 10 mins.
– Boil the pieces of fresh gumbo, cut into thin strips, in a little water for 15 to 20 mins; add a dash of potash (approximately 5 g).
– After steaming three times, mix the fonio with the gumbo sauce.
– Cook the aubergines and peppers in boiling water for 10 to 15 mins.
– Fry the finely chopped onions with the salt, stock cubes, black pepper and a dash of vinegar.
– Garnish the cooked fonio with the onion, pepper and aubergine sauce.

The cooking times are for guidance; fonio is properly cooked when the grain becomes fairly soft. The onion sauce can be prepared with meat or fish dumplings.

Boiled or gruel dishes

Niri fonye or *founden bande* is a typical Guinean dish, in which the fonio is boiled.

Niri fonye

Preparation and cooking time:

1 hour

Ingredients:

Whitened fonio (not precooked!)

Peanut sauce:

Peanut paste, meat or fish, fresh and/or pureed tomato, onion and/or garlic, gumbo (optional), salt, pepper, stock cube

Gumbo sauce:

Fresh gumbo, palm oil, meat or fish, onion, salt, pepper, stock cube

Preparation:

1. Fonio
– Grill fonio until it takes on a yellow colour.
– Boil water, and add the fonio.
– Remove a fair amount of the water; to be re-added gradually.
– Then cook at low heat.

2. Peanut sauce
– Dissolve the peanut paste in boiling water.
– Add the pre-crumbled meat or fish, and then the other ingredients.
– Leave to cook for 35 to 40 mins.

3. Gumbo sauce
– Chop the fresh gumbo.
– Put the chopped gumbo into the pot of water.
– Heat for 15 mins, stirring from time to time.
– Add the other ingredients.
– Boil for 25 to 30 mins.

In Guinea, Mali and Burkina Faso, so-called "fat fonio" (rice is also cooked in this way) is a hearty family dish.

Fat fonio

Preparation and cooking time:

45 mins to 1 h

Ingredients (for 5 people):

500 g to 1 kg precooked fonio, 500 g to 1 kg meat, chicken, or fish, 2 large onions, 6 large tomatoes, 6 medium carrots, 2 medium turnips, 2 medium courgettes, 2 medium aubergines, 2 small slices of cabbage, 1 large green pepper, 2 small red peppers, 5 small pieces of fresh gumbo, 2 tbsp tomato concentrate, 250 ml oil, iodized salt: to taste, spices, flavourings: laurel, pepper, stock cube, garlic, parsley, etc. – 2 L water

Preparation:

– Brown the meat (or fish or chicken), the sliced onions, the ground garlic and parsley, the peeled, deseeded and chopped tomatoes, and the tomato concentrate in oil.

– Add salt.
– Add 2 L of water, the spices and flavourings, and leave to cook for approx. 1 hour.
– When half-cooked, add the washed and evenly chopped vegetables.
– Remove the vegetables when they are cooked, set aside on a plate.
– Cook the meat to preference, check seasoning.
– Remove one or two ladles of stock and remove the meat (or fish or chicken). Add to the vegetables, and keep warm.
– Pour the precooked fonio into the rest of the stock, while stirring; the stock must cover the fonio.
– Cover the pot and leave on low heat, while stirring from time to time. If necessary, add some of the reserved stock.

Serve the fonio hot, garnished with the vegetables and meat (or fish or chicken), or serve separately.

Recently put on the market in Europe and the United States, and used by new consumers who cook it to their taste, fonio is the subject of many newly invented recipes, or recipes adapted from rice or wheat couscous dishes: taboulé or salads, fonio in milk sauce, fonio pudding or cakes, etc. The small grain size enables it to be used for original recipes, and to provide varied meals.

Fonio as a health food

"Let food be thy medicine and medicine be thy food," said Hippocrates more than twenty-four centuries ago. The inhabitants of fonio producing regions attribute a host of virtues to this cereal, sometimes not just nutritional. Besides raw fonio being applied to the body for its therapeutic effects on certain skin infections or diseases, fonio is often popularly held to be a food "for diabetics". This affirmation merits an explanation, as it is sometimes identified and trumpeted by certain non-specialist press, with the aim of promoting the benefits of this or that local or exotic product.

Fonio and diabetes

Diabetes, in particular type 2, is a disease increasingly affecting people worldwide, and particularly in urban Africa due to an unbalanced diet, often accompanied by excess weight aggravated by a sedentary lifestyle. Diabetics must seek to better balance their diet, particularly by reducing their calorie intake. Fonio is primarily a caloric food, like other cereals. Initial studies conducted by CIRAD, and later reported by the international NGO Santé Diabète, nevertheless showed that fonio has a glycemic index of around 57

(the benchmark, white bread, is 100), i.e. less than that of other cereals (except millet). The comparative evolution of blood glucose (mmol/l) with white fonio and white bread is illustrated in figure 10.1.

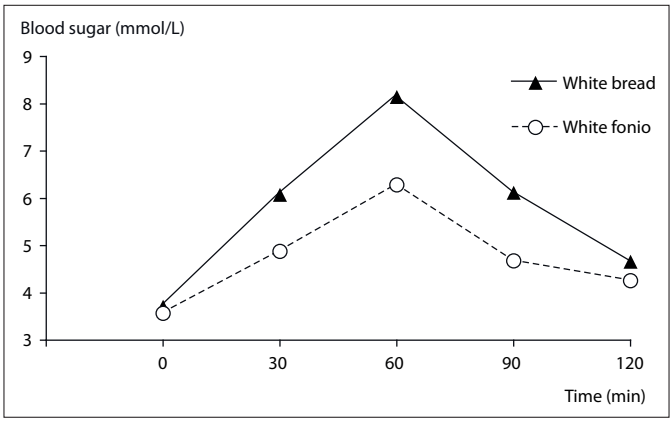


Figure 10.1. Comparative evolution of blood sugar (mmol/l) with white fonio and white bread (according to S. Besançon, CIRAD).

For diabetics, fonio may certainly be preferable to most other cereals, yet it should still be consumed in moderation, adhering to the quantities prescribed by doctors. Fonio is a highly digestible food which produces a relatively short-lived satiety. It is often regarded by the population as a light food that provides little nourishment and is free from sugars. Some diabetics may therefore eat too much fonio, which could lead to serious hyperglycaemia. Good nutritional education for patients is essential in order to prevent such risks. It should also be taken into account that dishes are often accompanied by sauces which are a major factor in the sugar content of a meal. Hence diabetics must avoid sauces rich in lipids (peanut), and favour more neutral sauces (gumbo, vegetables, etc.). Referring to the recipes described above, they can consume *foyo* with gumbo sauce, but should avoid *djouka*, *niri fonyé* or fat fonio! Further research is required to perfect our knowledge of fonio and how it can be beneficial in the diet of diabetics.

Fonio and gluten

The medical profession currently considers coeliac disease (or gluten intolerance) one of the most frequent gastro-intestinal diseases, affecting more than one in a thousand in the general population. It is manifested by an immune response, located in the small intestine, to ingesting foods containing gluten. The immunological and biochemical reactions involved

in gluten intolerance have not yet been clearly determined, and much research is still needed to find out the specific mechanisms of coeliac disease, and identify the proteins and peptides which are toxic for sufferers.

The term gluten is ambiguous, since there are several meanings, depending on the professionals using it. For the miller or baker, gluten is what gives flour made from hydrated and kneaded wheat, spelt, triticale, barley or rye the viscoelastic properties needed for bread making. Gluten is the viscous material left in the hand when washing flour, and all the starch has gone. For biochemists, gluten comprises the reserve proteins of the grain, prolamins and glutelins; which, in wheat, are gliadins and glutenins respectively; other proteins such as albumins and globulins are considered structural proteins. All cereals contain these four protein fractions in varying amounts.

Today, only certain prolamins have proven toxicity in coeliac disease, and in particular wheat α-gliadin, barley hordein and rye secalin. It would seem that it is actually particular sequences of amino acids frequently encountered in these prolamins which make them toxic to people with gluten intolerance. These sequences appear to be less frequent in oat prolamins (or avenins), which is sometimes tolerated in small quantities, and absent in prolamins of other cereals, like maize zein, sorghum kafirin, and rice orzenin; these cereals are tolerated quite well.

Fonio contains the four common protein fractions of cereals, but appears richer in glutelins ("digitenins") than prolamins, as table 10.1. below shows. It was drawn up by researchers at the University of Leeds in the United Kingdom (Jideani *et al.*, 1994).

Table 10.1. Comparative protein fractions of fonio and durum wheat, using the Osborne method.

Protein fraction	Fonio	Durum wheat
Albumin	3.5	11.0
Globulin	1.8	7.0
Prolamin	5.5	42.0
Glutelin	14.0	30.0
Residues	55.2	7.8

Like sorghum and maize, fonio is genetically closer to millet (sub-family Panicoideae) than wheat or barley (sub-family Pooideae). As is the case for these two cereals, fonio has no toxic effects for people with a gluten intolerance.

Fonio and quinoa

A comparison between fonio and quinoa is an interesting and worthwhile exercise.

Quinoa *(Chenopodium quinoa)* is a small grain traditionally grown in the high valleys of Bolivia and Peru, because of its very good adaptation to the poor, arid soils of the Andean plateaux. Quinoa, which is not a Gramineae but a Chenopodiaceae (spinach and beet family) is often dubbed a "pseudo-cereal". It was long neglected, and deemed a "food of the poor" or "food for Indians", until its nutritional and dietetic qualities were rediscovered, in particular its richness in "gluten-free" proteins.

Today, quinoa is highly successful on the US and European markets, and the emergence of fair trade industries is ensuring stable outlets and sizable revenue for producers, thanks to the added value of their finished product. In Northern countries, sustained media coverage is informing consumers, who are often won over by this "new", original and exotic grain, which also has a mythical quality through association with the Inca culture.

Yet many voices have recently been raised to denounce the adverse effects of this sudden fame. They say that quinoa has gradually gone from being a subsistence activity to an export crop, causing a steep rise in its cost and reducing biodiversity, retaining only one variety with large white grains to cater to the preferences of "Northern consumers". Quinoa, which has become too expensive, is apparently no longer consumed by producers themselves, who prefer to sell it, and feed themselves with imported products. Given its success, certain companies and American academics have set their sights on it, and have even tried to patent a variety, fortunately without success.

Certain criticism may be excessive, but all those interested in fonio and securing its added value have to take this experience into account. They must remain vigilant to ensure that the development of the fonio industry does not fall into these traps, but contributes to improving the profitability and sustainability of production systems.

Conclusion

In this work, among the first — if not the first — dedicated exclusively to fonio, we aimed to compile what information there is available, some of which is very dated, on this little African cereal, neglected for so long. The recent implementation of a few international projects which bring together African and European researchers, and local women processors, has helped develop innovative practices, in particular at the post-harvest level. This provides hope for a resurgence in interest from decision makers, and above all, producers and other industry players.

Perceptions of fonio are changing. Long relegated to the rank of a rustic cereal and deemed a "food of the poor", often synonymous with food shortages, fonio appears to be acquiring a new lofty status as a cereal prized by urban consumers, and even exported. This newfound fame is sometimes exaggerated when certain blogs or websites call it the "cereal of the 21st Century," yet its good resistance to drought make it a plant that is well-adapted to climate change. Its nutritional qualities – its richness in sulphur amino acids and "gluten free" proteins – also make it very interesting, even though fonio remains a food very similar to rice.

Today, thanks to technological advances made through research, fonio can be found in supermarkets in major cities in West Africa, and is regularly exported, in small quantities, to Europe and the United States, where natural products and new dishes are in vogue. The gradual development of organic and fair trade industries may eventually provide fonio producers with better revenue and potentially revitalise its cultivation in zones where it has been gradually abandoned; however, this development must be properly thought out and controlled, to avoid falling prey to "quinoa syndrome".

Northern countries already have their own "rustic" cereals (spelt, einkorn, oats, rye, etc.) or "gluten free" cereals (rice, maize, buckwheat, etc.). Hence the development of fonio farming should primarily focus on feeding Southern cities, and in particular producer countries themselves. The requirements of consumers from Southern cities are often comparable to those of Northern consumers, and concern hygienic, nutritional, culinary and organoleptic qualities, as well as product diversification. Support must be provided to local women processors, who in many cases have little in the way of technical and financial resources. Further research endeavours (in the form of public/private partnerships) are also necessary in the fields of genetic resources (varieties), agronomy (ecological intensification, sustainable production

systems), post-harvesting, technology (washing, degritting, parboiling, packaging processes) and food science (new products), to fully meet these expectations, and thereby contribute to the renewal of fonio, an original African cereal.

Glossary

Allogamy: System of cross-fertilisation reproduction, i.e. the fertilising pollen comes from another plant. As opposed to autogamy, which is self-fertilisation of a plant.

Amylose: Constituent of starch formed by unbranched chains of glucose molecules. The main constituent of starch is amylopectin (branched chains of glucose). Amylose levels vary between cereals.

Banco: A clayey form of adobe, enriched with cereal straw and used as a construction material for building various structures (houses, granaries).

Biodiversity: Variety of living species populating the biosphere.

Bran: By-product or co-product of processing, obtained after grain whitening. The bran, comprising fragments of pericarp and germ, are rich in fibres, fatty matter and vitamins, and is often re-used in animal feed.

Campaign: The agricultural campaign is a production period or seasonal production cycle.

Caryopsis: A simple dry fruit on a grass plant, obtained after fertilisation of the flower. The caryopsis is more commonly called the grain.

Corneous grain: Grain with a naturally hard and translucent endosperm, with a compact structure, in contrast to floury grains with a friable structure, and yielding a white flour.

Cowpea: A small black-eyed bean (*Vigna unguiculata*), commonly cultivated in West Africa.

Crabgrasses: Annual herbaceous plants, the inflorescence of which comprises several thin spikes arranged a bit like the fingers on a hand.

Crop rotation: Alternating different crops from year to year to regenerate the soil after each harvest. Crop rotation is often considered the lynchpin of sustainable agriculture.

Cropping plan: Division of farm land into distinct parts or plots.

Cultivar: Variety obtained by selection over successive cultivations.

Cyclone collector: System for recovering fine particles such as bran or dust.

Daba: Traditional African hoe, generally with a short handle. The shape of the *daba* varies greatly between regions, the job to be done (soil working, hoeing or ridging), or the soil type (sandy, clayey, etc.).

Desertification: Degradation of the earth and plant cover in dry zones because of human activity and climate change.

Dogon people: The Dogon are a traditional people from Mali who live in the Mopti region and more specifically either side of the Cliff of Bandiagara (Bandiagara plateau and Séno plain).

Draught cultivation: Draught cultivation consists in using animals (horses, donkeys, mules or oxen) to draw tools or machines required to carry out certain agricultural operations (working the soil, sowing and maintenance, or harvesting).

Dry land rice: Rice produced without submerging the plot, using natural rain watering.

Ecotype: A "local variety" which may be heterogeneous. This heterogeneity is a source of diversity.

Edaphic: Pertaining to relationships between soil and plants.

Fair trade: Fair trade is a form of social trade based on dialogue, transparency and respect, and which aims for greater fairness in exchanges between producers, processors and consumers.

Fallow: Farmable land temporarily left free from crops to restore a soil depleted by a succession of crops.

Family agriculture: Agriculture based on a family workforce, which is often synonymous with peasant farming, in particular in developing countries.

Feeding hopper: A container placed above a machine to fill it with grain.

Ferralitic: Red-coloured tropical soil, rich in iron hydroxides and aluminium, derived from weathering of the mantle rocks.

Fertiliser: Amendment applied for the purpose of soil improvement. Organic fertilisers are plant or animal waste, which is reincorporated into the soil. The contrasting form is chemical fertilisers.

Fertilization: Inputting fertilisers and amendments to maintain or improve soil fertility. The main fertilisers are nitrogen (N), phosphorus (P) and potassium (K).

Fesro: Traditional dish from north-west Cote d'Ivoire, which is a kind of "fat fonio", where the fonio grains are initially cooked with a little fatty matter (oil), as is the case when preparing "fat rice".

Food crop farming: Agriculture primarily intended for self-consumption and selling the produce on local markets. Food crop farming is most common in developing countries.

Friction: Principle of cereal processing, consisting in promoting "grain-grain" friction for the purpose of whitening.

Fula people: An ethnic group of nomadic and semi-nomadic livestock farmers, now partly settled in many Sudano-Sahelian countries, where they are still engaged in farming.

Glumaceous: With lemmae.

Glumes: Bracts surrounding the base of the spikelets in Gramineae.

Glycaemic index: Index characterising the hyperglycaemic capacity of a food, against a benchmark carbohydrate (index 100 for glucose in water or white bread).

Grain processing: General term used for all the technology operations performed on the grains, such as hulling, whitening and milling.

Gramineae or **Poaceae**: Family of very common plants, which includes cereals and many grasses.

Green Revolution: Policy or model of agricultural development from the 20th century, based on intensification of agricultural production.

Growth cycle: The various development stages between seed germination and plant maturity.

Gumbo: Tropical plant, the fruit of which is used to prepare a highly glutinous sauce which is an ingredient of many African dishes. Fonio and gumbo are often associated.

Hard lateritic crust: Pan or crust formed by hardening of a red ferralitic soil in tropical countries. These are known as duricrust soils.

Harrowing: A cultivation operation consisting in breaking up the large clods of earth after ploughing to obtain mellowed land fit for sowing. Harrowing is also carried out to bury broadcast seeds.

Hilum: The attachment point of the grain with the stock plant from which it grew. The hilum on cereals appears in the form of a scar at one end of the grains.

Hoeing*:* Hoeing consists in breaking the surface crust of the soil to mellow and aerate it. Hoeing is often associated with weeding.

Homestead field*:* Fields situated close to homesteads, used for continuous cultivation. In these fields, enriched by ash, manure or other waste, fruit trees are planted. They also produce vegetables, and early or demanding crops.

Hulling: Post-harvest operation consisting in removing the external shell from the grains.

Hulls: External shells (glumes, lemma and palea) present on dressed cereal grains (rice, fonio, barley, oats, spelt, etc.). The hulls represent 20 to 25% of the gross weight.

Hydromorphic*:* Type of soil which is regularly water saturated, or which has signs of waterlogging.

Input: Product used to improve crop production (fertilisers, phytosanitary products).

Isohyet: Imaginary line connecting the points of a zone with the same annual precipitation level.

Layot: A small straw basket which is used as a sieve. Term used many times by René Caillé when describing cleaning of fonio or wild fonio.

Lean season: The difficult period (often June to August) which separates depletion of the granary reserves from the next harvest.

Legumes: Plants which bear a pod (bean, pea, broad bean, cowpea, soy, etc.), and which are richer in proteins than cereals. Legumes are able to fix atmospheric nitrogen by means of a symbiotic association with bacteria (see "nodules").

Lemma and palea: Bracts which form the outer shell of each flower, in Gramineae.

Lodging: State of cereals or legumes whose stems lie on the soil, generally due to wind and rain.

Lougan: In Africa, a plot or field cultivated in the bush (slashed and burned).

Mandingo: Group of West African peoples originating from Mali. The Malinké, Bambara, Dialonké and Sarakolé (Soninké) are part of the Mandingo group.

Mat*:* Mat made from woven straw, often used for natural drying of agricultural and food products.

Mechanisation: Development or use of machinery on farms or agricultural product processing units.

Moisture content: The moisture content of grains is the ratio, expressed as a percentage, between the mass of water contained in a sample of grains, and the total mass of the sample. "Wet base" signifies that the measurement is taken on wet matter (total mass), rather than dry matter.

Monocot: Plant whose seeds have only one cotyledon (e.g.: cereals), as opposed to plants with two cotyledons (e.g.: legumes).

Monoculture: Agricultural practice consisting of planting a single species on farms. Monoculture may cause ecological imbalances.

Mougou témé: The various sieves used by the operators for sifting fonio grains are *mougou témé* (1 mm), *klantié témé* (1.5 mm), *bassi témé* (2 mm), *wara wara* (2.5 mm) for breaking up the fonio after steaming, for example, and *nylon témé* (< 1 mm) for bran or flour.

Nematodes: Nematodes (or Nemathelminthes) are tiny worms, often invisible to the naked eye, which live in the soil, and some of which parasitically attack plants.

Niche market: A very narrow market segment, corresponding to a specific clientele, and associated with a highly specialised product.

Nodules: Organs (elongated or round swellings) observed on the roots of legumes, containing atmospheric nitrogen-fixing bacteria.

Nutrient element*:* Mineral which a plant needs to be able to develop and grow normally.

Nutrients: Various nutrient elements essential to the physiology of organisms. Major plant nutrients are phosphates, nitrates, mineral salts and potassium.

Oilseed*:* A seed (peanut, sesame, colza, sunflower, etc.) rich in oil.

Organic agriculture*:* Agriculture which does not use synthetic chemicals (fertilisers, pesticides) or GMOs (genetically modified organisms).

Organic soil amendment*:* A fertiliser mainly comprising organic matter of plant and animal origin, which is applied to improve the physical and biological properties of cultivated soils.

Parboilers: Utensils (pots, drums, machines, etc.) used for parboiling grains, and by extension, the women carrying out the parboiling operation.

Pedicel*:* A small stalk bearing a flower at its crown (or spikelet in the case of fonio).

Pegu: this term, cited by the anthropologist Denise Paulme, refers to *Lannea acida* of the family Anacardiaceae. The fruits of this small bush are used by the Dogon to prepare a very sweet drink.

Pericarp: The pericarp is the wall of the fruit, or for cereals, the "skin" of the grain or caryopsis.

Pesticide: A chemical designed to eliminate pests and plants considered harmful, but also a major source of pollution.

Pests: This term most commonly refers to insects and rodents which attack grain reserves, and cause considerable losses.

Piedmont plain: Plain situated at the foot of a mountain range.

Pistache: In Africa, this term often corresponds to the peanut ("*pistache de terre*"), or maybe the bambara nut (voandzou). In Haiti too, the peanut is referred to as "*pistache*".

Ploughing: Action of turning the earth using a plough, fork, etc., to aerate it and prepare it for sowing.

Polyculture*:* An agricultural practice consisting of producing several crops on the same farm. Unlike monoculture, polyculture helps balance the agricultural ecosystem, by increasing biodiversity.

Post-harvest: Operations performed after harvesting, which for cereals include in particular the main technical activities of threshing, cleaning, drying, storage, and processing.

Primo-domestication: Start of domestication, or control of plant development, by human communities.

Rainy season: The period of heavy rains in tropical countries, i.e. from June to October in West Africa.

Raceme: Simple inflorescence (spikelets in the case of fonio).

Reaping: Harvesting operation which consists in cutting the stems using a knife, sickle or scythe.

Roselle (or sorrel): This refers to *Hibiscus sabdariffa* L., a herbaceous plant from West Africa, whose red flowers are used to prepare a drink known as *"bissap"*, *"karkadé"* or *"dah"*. In her article "Plant classification among the Dogon", Germaine Dieterlen reiterates that: "the two essential seeds of the "collarbones of the Keita", the founders of the Mali Empire, are fonio (*fani*) and roselle (*da*)." (Dieterlen, 1952).

Safe moisture content: Product moisture content below which micro-organisms, and in particular moulds, cannot develop during storage.

Semi-arid: Character of a climate in which summer precipitation does not exceed 800 mm/year.

Shifting cultivation: Cultivation system in which a field is cleared and cultivated for a few years before being left fallow. Shifting cultivation is an effective system, but requires large areas of uncultivated fallow land.

Silt: Fine soil particles, 2 to 20 µm in size for fine silts, and 20 to 50 µm for coarse silts.

Slash-and-burn*:* Clearing method in which the ligneous plants are cut down, leaving the biggest trees, and then burning the crowns when they have dried. This is the usual method of clearing forests or wild land.

Soil fertility: This is the ability of a soil, field or region to produce harvests. It is dependent on the climate, soil and techniques applied.

Sorption isotherm: Curve representing, at a given temperature, the moisture content of a product as a function of the water activity value (or relative air moisture content at equilibrium).

Sudano-sahelian: Climate zone in the southern Sahel, characterised by a long dry season, and a single, very short rainy season, with annual precipitation of between 500 and 900 mm.

Soumbala*:* Traditional West African condiment, known as "*nététou*" in Senegal, made from néré seeds (cooked, husked, fermented, salted, dried). This product is often packed in pellet form.

Sowing: Cultivation operation consisting in sowing the seeds. Fonio is generally "broadcast" sown.

Spikelet*:* Small spike of a few flowers, two in the case of fonio (one fertile flower and one sterile flower).

Starch: Complex carbohydrate formed of glucose molecules. Starch represents the energy reserve of cereal grains.

Stream inland valley: The flat or concave bottom parts of dells and small valleys where surface waters converge. Fonio is never cultivated in these submerged stream inland valleys for part of the year, when rice is grown more.

Sustainable agriculture: Agriculture aimed at preserving natural resources (soil, water, air, biodiversity) in the long term.

Tapade: An enclosure within a smallholding in Fouta-Djalon, Guinea. The word *tapade* is a Franco-Guinean term, apparently derived from the Portuguese *tapar:* close.

Threshing*:* In agriculture, threshing is a post-harvest operation which consists in separating grains from the spike or stem.

Tillering: Ability to produce numerous secondary stems (or ears) in Gramineae. These branches form at the bottom of the plant on the tillering base.

Tô: Traditional African dish consumed every day in certain countries like Mali, Burkina Faso, northern Côte d'Ivoire and Togo; it is a paste (or thick gruel) based on cereal flours (millet, sorghum, maize or fonio).

Toposequence*:* Succession of soils, which are distinguished primarily by their topography.

Trampling: Threshing technique whereby horses, mules or oxen trample the sheaves to separate the grains; a tractor may also be driven over them to achieve the same effect.

Water activity: Represented by the symbol a_w, this represents the availability of water in products. It is equal to the ratio between water vapour pressure on the surface of a product and the saturating vapour pressure at the same temperature. Pure water has an a_w of 1.

Weed: A weed is an undesirable plant foreign to a sown plot, which grows spontaneously among a crop. Weeds are often referred to as "crab grass".

Weeding: Action which consists in uprooting weeds by hand or with a tool. Weeding is often associated with hoeing, the aim of which is to break the soil crust to aerate it.

Whitening: Processing operation which consists in eliminating the pericarp and germ from the grains to retain only the endosperm. This operation follows hulling.

Winnowing: Cleaning the threshed grains to separate them from their impurities (hulls, stems portions, dust) using a winnowing basket, using the effect of an air current.

Winnowing basket: Sort of flat woven straw basket used for cleaning grains by winnowing.

Women processors: Women who process local products for added-value uses. In Africa, these very dynamic women processors sometimes work in women's groups, or create and manage small processing companies.

Yield: In agriculture, the yield is the quantity of product harvested in a given surface area. It is expressed in kilograms (kg) per hectare, tonnes (1 t = 1,000 kg) or in hundredweight (1 q = 100 kg) per hectare.

References

Aboua F., Nemlin J., Kossa A., Kamenan A., 1989. Transformation traditionnelle de quelques céréales cultivées en Côte d'Ivoire. *In : Céréales en régions chaudes*, Aupelf-Uref, John Libbey Eurotext, Paris, 223-229.

Adoukonou-Sagbadja H., Wagner C., Ordon F., Friedt W., 2010. Reproductive system and molecular phylogenetic relationships of fonio millets *(Digitaria spp.*, Poaceae*)* with some polyploid wild relatives. *Tropical Plant Biol.*, 3 (4), 240-251.

Adoukonou-Sagbadja H., Schubert V., Dansi A., Jovtchev G., Meister A., Pistrick K., Akpagana K., Friedt W., 2007. Flow cytometric analysis reveals different nuclear DNA contents in cultivated fonio *(Digitaria spp.)* and some wild relatives from West Africa. *Plant Systematics Evol.*, 267, 163-176.

Ag Bendesh M., Chauliac M., 1998. Alimentation de rue, mutations urbaines et différenciations sociales à Bamako (Mali). *Cahiers Santé*, 2 (16), 33-57.

André V., Pestaña G., 2002. Les visages du Fouta-Djalon. *Les Cahiers d'Outre-Mer*, 217,63-88.

Aune J.B., 1991. Régénération des plaines à *Panicum laetum* dans le Gourma malien. *Revue d'Élevage et de Médecine Vétérinaire des Pays Tropicaux*, 44 (3), 363-372.

Balachowsky A.S., 1954. Le Fouta-Djalon en Moyenne Guinée. *La Nature, Revue des Sciences et de leurs Applications*, janvier 1954, 3227, 83-88.

Baudet J.C., 1981. *Les céréales mineures : bibliographie analytique*, Agence de Coopération Culturelle et Technique, Paris, 38-48.

Béavogui F., Cissé S., Friebl M., Pedelahore P., 1992. Suivi de culture : le fonio, document multigraphié, Irag, Cra, Kankan, Guinée, 18 p.

Bourdillat F., 1995. Les voies d'amélioration de la culture du fonio dans les plaines de Timbi, mémoire de fin d'études, document multigraphié, Istom, Irag, Guinée, 60 p.

Busson F., 1965. Étude chimique et biologique des végétaux alimentaires de l'Afrique noire de l'Ouest dans leurs rapports avec le milieu géographique et humain, thèse présentée à la faculté des Sciences de l'université d'Aix-Marseille, 568 p.

Caillé R., 1830. *Voyage à Tombouctou*, 2 tomes, réédition de 1989, La Découverte, Paris.

Carcea M., Acquistucci R., 1997. Isolation and physicochemical characterization of fonio (*Digitaria exilis* Staph) starch. *Starch/Stärke*, 49 (4), 131-135.

Ceemat, 1975. *Manuel de culture avec traction animale*, collection Techniques rurales en Afrique, ministère de la Coopération, Paris, 336 p.

Chantereau J., Cruz J.F., Ratnadass A., Trouche G. 2013. Le sorgho. Collection Agricultures tropicales en Poche, Quæ, Cta, Presses agronomiques de Gembloux, 175 p.

Chantereau J., Nicou R., 1991. *Le Sorgho*, Maisonneuve et Larose, Paris, 159 p.

Chevalier A., 1909. Les hauts plateaux du Fouta-Djalon. *Annales de Géographie*, 18 (99), 253-261.

Cruz J.F., 2016. Amélioration de l'après récolte et valorisation du fonio en Afrique. Projet Aval Fonio. Rapport Final. Cirad Montpellier, 45p.

Cruz J.F., 2014. Improvement of post-harvest and enhancement of fonio in Africa. Aval Fonio project. Annual report. CIRAD, Montpellier, 36p.

Cruz J.F., 2012. Fonio. *In* Poulain J.P. (dir.), Dictionnaire des cultures alimentaires, Paris, Quadrige collection. Presses universitaires de France, Paris, 594- 601

Cruz J.F., 2011. Amélioration de la qualité et de la compétitivité de la filière fonio en Afrique de l'Ouest. Projet Fonio, [CD-Rom], Cirad, Montpellier, France.

Cruz J.F., 2009. Le fonio, une céréale ancestrale remise au goût du jour. *Travaux et Innovations (La revue des agents du développement agricole et rural)*, 163, 28-31.

Cruz J.F., 2008. La filière fonio en Afrique de l'Ouest. Conférence Fonio de Bamako, avril 2008, [CD-Rom], Cirad, Montpellier, France.

Cruz J.F., 2004. Fonio: a small grain with potential. *Leisa (magazine on low external input and sustainable agriculture. Valuing crop diversity)*, 20 (1), 16-17.

Cruz J.F., 2001. *Le fonio*, document multigraphié, Cirad, Montpellier, France, 24 p.

Cruz J.F., Kébé C. M.F., Goli T., Diallo T.A., Guindo F., Medah I., Ferré T., Thaunay P., Béavogui F., Sambou V., Cissé M., Soufountera M. 2014. Mécanisation post-récolte du fonio. [Poster]. *In* : Congrès international sur les aliments traditionnels africains AFTER (African food tradition revisited by research). Valorisation des aliments traditionnels africains : innovations, qualité et accès au marché. 11-12 novembre 2014, Dakar, Sénégal.

Cruz J.F., Rivier M., Fliedel G. 2009. Étuvage du fonio : essais expérimentaux à Bamako (Mali). In : Amélioration de la qualité et de la compétitivité de la filière fonio en Afrique de l'Ouest (J.F. Cruz, éd.), [CD-Rom], Cirad, Montpellier, 32 p.

Cruz J.F., Marouzé C., Rivier M., Méot J.M., Drame D., Diarra M., Tangara K., Yalcouyé D., 2008. Amélioration de la qualité du fonio. Développement de séchoirs [Poster]. *In* : *La filière fonio en Afrique de l'Ouest* (J.F. Cruz, éd.), [CD-Rom], Cirad, Montpellier, Conférence Fonio, 28 avril 2008, Bamako, Mali.

Cruz J.F., Dramé D., 2005. Technologies post-récolte du fonio. Projet CFC - Amélioration des technologies post-récolte du fonio, [CD-Rom], Cirad, Montpellier, France.

Cruz J.F., Troude F., Griffon D., Hebert J.P., 1988. *Conservation des grains en régions chaudes*, 2e édition, ministère de la Coopération et du Développement, Paris, 545 p.

Daho B., Vall É., Dembélé K., Beavogui F., Diallo T. A., Sogodogo D., 2007. Place du fonio dans le système de production, priorités pour renforcer la place du fonio dans l'économie des ménages, Projet Fonio. *In : Amélioration de la qualité et de la compétitivité de la filière fonio en Afrique de l'Ouest* (J.F. Cruz, éd.), [Cd-Rom], Cirad, Montpellier, 22 p.

Dalziel J.M., 1937. *The Useful Plants of West Tropical Africa*, Crown agents for the colonies, London, 526.

De Wet J.M.J., 1995. Minor cereals. *In : Evolution of Crop Plants* (J. Smartt and N.W. Simmonds, Eds), 2nd edition, Longman, London, 202-208.

Diallo T. A., Fliedel G., Stilmant D., Cruz J.F., 2008. Catalogue de quelques écotypes de fonio de Guinée, du Mali et du Burkina Faso. Projet Fonio. *In : Amélioration de la qualité et de la compétitivité de la filière fonio en Afrique de l'Ouest* (J.F. Cruz, éd.), [CD-Rom], Cirad, Montpellier, 48 p.

Diallo T.A., 2003. Connaissances endogènes sur le fonio en Guinée. *In* : *Actes*

du premier atelier sur la diversité génétique du fonio (Digitaria exilis Stapf*) en Afrique de l'Ouest* (S.R. Vodouhè, A. Zannou et E. Achigan Dako, éds), 4-6 août 1998, Conakry, Guinée, IPGRI, Rome, 42-44.

Dieterlen G., 1952. Classification des végétaux chez les Dogon. *Journal de la Société des Africanistes*, Paris, 22, 115-158.

Dramé D., Cruz J.F., 2002. Amélioration des technologies post-récolte du fonio, rapport de mission au Bénin et au Sénégal, Coraf (Conseil Ouest et Centre africain pour la recherche et le développement agricoles), 24 p.

Dudgeon G.C., 1922. *The Agricultural and Forest Products of British West Africa*, 2nd edition, collection Imperial institute handbooks, J. Murray, London, 176 p.

Dury S., Meuriot V., 2011. Do urban African dwellers pay a premium for food quality and, if so, How much? An investigation of the Malian fonio grain market. *Review of Agricultural and Environmental Studies*, 91 (4), 417-433.

Dury S., Meuriot V., Fliedel G., Blancher S., Bore Guindo F., Drame D., Bricas N., Diakite L., Cruz J.F., 2007. The retail market prices of fonio reveal the demand for quality characteristics in Bamako, Mali. *In*: *Pro-poor development in low-income countries: food, agriculture, trade and environment*, *106th Seminar of the European Association of Agricultural Economists (EAAE),* October 2007, Montpellier, France, 15 p.

Fliedel G., Ouattara M., Grabulos J., Drame D., Cruz J.F., 2004. Effet du blanchiment mécanique sur la qualité technologique, culinaire et nutritionnelle du fonio, céréale d'Afrique de l'Ouest. *In : Voies alimentaires d'amélioration des situations nutritionnelles en Afrique de l'Ouest : le rôle des technologues alimentaires et des nutritionnistes, actes du 2e Atelier international* (D. Brouwer Inge, S. Traoré Alfred., S. Trèche, éds), 23-28 novembre 2003, Ouagadougou, Presses universitaires de Ouagadougou, Burkina Faso, 599-614.

Fogny-Fanou N., Koreissi Y., Dossa R.A.M., Brouwer I.D., 2009. Consumption of, and beliefs about fonio *(Digitaria exilis)* in urban area in Mali. *African Journal of Food, Agriculture, Nutrition and Development*, 9 (9), 1927-1944.

Gallais J., 1959. La riziculture de plaine en Haute Guinée. *Annales de Géographie*, 68 (367), 207-223.

Garreau J.M., 1993. Étude des systèmes de production dans la région de Timbi-Madina en République de Guinée, document multigraphié, Cnearc/Eitarc, Montpellier, France, 94 p.

Gigou J., Stilmant D., Diallo T.A., Cissé N., Sanogo M.D., Vaksmann M., Dupuis B., 2009. Fonio millet (*Digitaria exilis*) response to N, P and K fertilizers under varying climatic conditions in West Africa. *Experimental Agriculture*, Cambridge University Press, 45, 401-415.

Gigou J., Giraudy F., Doucouré C.O.T., Healy S., Traoré K., Guindo O., 2004. L'âge des champs : un indicateur du passage de la culture itinérante à la culture permanente dans le bassin cotonnier du Mali. Évolution des pratiques et dynamique des territoires. *Cahiers Agricultures*, 13 (6), 467-472.

Goli T., Thaunay P., Ricci J., Prades A., Bore Guindo F., Babre D., Van de Lee A., Cruz J.F. 2014. Procédés de dessablage du fonio. Détermination de la teneur en sable. [Poster]. *In* : Congrès international sur les aliments traditionnels africains AFTER (African food tradition revisited by research). Valorisation des aliments traditionnels africains : innovations, qualité et accès au marché. 11-12 novembre 2014, Dakar, Sénégal.

Guillaume, Portères, Guilloteau, Maistre, 1949. Le problème rizicole dans les territoires africains de l'Union française. *L'Agronomie Tropicale*, 4 (7-8), 339-378.

Haq N., Dania Ogbe F., 1995. Fonio (*Digitaria exilis* and *D. iburua*). *In* : *Cereals and Pseudocereals* (J.T. Williams, Ed.), Chapman and Hall, London, 225-245.

Havinden M.A., 1970. The history of crop cultivation in West Africa: a bibliographical guide. *Economic History Review*, 23 (3), 532-555.

Heim De Balsac F., Fernbach E., Husson M., Maheu J., 1931. Le grain de fonio, valeur alimentaire, essais de fermentation. Travaux du Service d'études des productions coloniales - Productions et cultures coloniales. Technologie, Biotechnie coloniales, *Bulletin de l'Agence Générale des Colonies*, Paris, 271, 1329-1340.

House L.R., 1995. Sorghum and millets: history, taxonomy, and distribution. *In: Sorghum and Millets, Chemistry and Technology* (D.A.V. Dendy, ed.), AACC, Minnesota, United States, 1-10.

Ibn Battûta, 1982. *Voyages III. Inde, Extrême-Orient, Espagne et Soudan*, collection FM/La Découverte, Librairie François Maspero, Paris, 456 p.

Irving D.W., Jideani I.A., 1997. Microstructure and composition of *Digitaria exilis* Staph (acha): a potential crop. *Cereal Chemistry*, 74, 224-228.

Jacques-Félix H., 1963. *Contribution de René Caillé à l'ethnobotanique africaine au cours de ses voyages en Mauritanie et à Tombouctou : 1819-1828*, Orstom, Paris, 172 p.

Jideani I.A., Takeda Y., Hizukuri S., 1996. Structures and physicochemical properties of starches from acha (*D. exilis*), Iburu (*D. iburua*) and tamba (*E. coracana*), *Carbohydrates*, 73 (6), 677-685.

Jideani I.A., Owusu R.K., Muller H.G., 1994. Proteins of acha (*Digitaria exilis Stapf*): Solubility fractionation, gel filtration, and electrophoresis of protein fractions, *Food Chemistry*, 51, 51-59.

Jumelle H., 1912. *Les cultures coloniales. Plantes à fécule et céréales*, Paris, 103-104.

Konkobo-Yaméogo C., Chaloub Y., Kergna A., Bricas N., Karimou R., Ndiaye J.L., 2004. La consommation urbaine d'une céréale traditionnelle en Afrique de l'Ouest : le fonio. L'alimentation des villes. *Cahiers Agricultures*, 13 (1), 125-128.

Labouret H., 1937. La géographie alimentaire en Afrique Occidentale. *Annales de Géographie*, 46 (264), 591-610.

Leplaideur M.A., Seck M., Ouattara S., 1994. Le Sahel contre-attaque. *In : L'Afrique, côté cuisines* (Syfia), Éditions Syros et Fondation pour le progrès de l'homme, Paris, 115-119.

Lhoste P., Havard M., Vall É., 2010. *La traction animale*, collection Agricultures tropicales en poche, Quæ, CTA, PAG, 223 p.

Marouzé C., Thaunay P., Fliedel G., Cruz J.F., 2008. Designing a fonio mill, screening an operating principle and its validation. *Agricultural Mechanization in Asia, Africa and Latin America*, 39, 9-15.

Marouzé C., Dramé D., Brouat J., Coulibaly B., 2005a. Crible rotatif long (CRL), dossier de fabrication : version manuelle et version motorisée. Projet Fonio CFC/ICG - Projet Fonio CFC/ICG - Amélioration des technologies post-récolte du fonio, Cirad, IER, Irag, Irsat, L'Harmattan, Paris, 26 p.

Marouzé C., Thaunay P., Dramé D., Diop A., 2005b. Canal de vannage pour grains et graines, dossier de fabrication. Projet Fonio CFC/ICG - Amélioration

des technologies post-récolte du fonio, Cirad, IER, Irag, Irsat, L'Harmattan, Paris, 38 p.

Marouzé C., Thaunay P., Dramé D., Loua F., Son G., Diop A., 2005c. Décortiqueur à fonio GMBF, dossier de fabrication. Projet Fonio CFC/ICG - Amélioration des technologies post-récolte du fonio, Cirad, IER, Irag, Irsat, L'Harmattan, Paris, 43 p.

Mazoyer M., Roudart L., 1997. *Histoire des agricultures du monde. Du néolithique à la crise contemporaine*, Seuil, Paris, 534 p.

Morales-Payán J.P., Ortiz J.R., Cicero J., Taveras F., 2002. *Digitaria exilis* as a crop in the Dominican Republic. *In: Trends in New Crops and New Uses* (J. Janick and A. Whipkey, Eds), ASHS Press, Alexandria, Virginia, United States, S1-S3.

Mugnier J., 2001. La nouvelle classification des plantes à fleurs. De la graine à la plante. *Pour la science*, Belin, Paris, 60-68.

Ndiaye M., Termorshuizen A. J., van Bruggen A.H.C., 2008. Effect of rotation of cowpea (*Vigna unguiculata*) with fonio (*Digitaria exilis*) and millet (*Pennisetum glaucum)* on *Macrophomina phaseolina* densities and cowpea yield. *African Journal of Agricultural Research*, 3 (1), 37-43.

Niangado O., Kebe D., 2002. *Enjeux des droits de propriété intellectuelle pour la recherche agricole et la filière des semences en Afrique de l'Ouest et du Centre.* Chapitre 7. Commerce, propriété intellectuelle et développement durable vus de l'Afrique, ICTSD, Enda, Solagral, 127-141.

Nolle J., 1986. *Machines modernes à traction animale : itinéraire d'un inventeur au service des petits paysans*, Paris, L'Harmattan, 478 p.

NRC (National Research Council), 1996. Lost crops of Africa, Vol.1: grains. Board on Science and Technology for International Development, National Academy Press, Washington D.C., 59-75.

Paulme D., 1940. *Organisation sociale des Dogon*, Domat-Montchrestien, Paris, réédition 1988, éditions Jean-Michel Place, Paris, 595 p.

Perrot É., 1929. Sur les productions végétales indigènes ou cultivées de l'Afrique Occidentale Française, rapport de mission, Office national des matières premières végétales, Paris, 468 p.

Portères R., 1976. African cereals: Eleusine, Fonio, Black Fonio, Teff, Brachiara, Paspalum, Pennisetum and African Rice. *In: The Origins of African Plant Domestication* (J. Harlan, J.M.J. de Wet and A.B.L Stemler, Eds), The Hague: Mouton, 409-451.

Portères R., 1955. Les céréales mineures du genre Digitaria en Afrique et en Europe. *Journal d'Agriculture Tropicale et de Botanique Appliquée*, 2, 349-386, 477-510, 620-675.

Portères R., 1951. Une céréale mineure cultivée dans l'Ouest-africain (*Brachiaria deflexa* C.E. Hubbard). *L'Agronomie Tropicale*, 6 (1-2), 38-42.

Portères R., 1946. L'aire culturale du *Digitaria Iburua* Stapf., céréale mineure de l'Ouest-Africain, *L'Agronomie Tropicale*, 1 (11-12), 589-592.

Purseglove J.W., 1985. *Tropical Crops. Monocotyledons*, Harlow, United Kingdom, 142-144.

Rançon A., 1894. *Dans la Haute Gambie. Voyage d'exploration scientifique 1891-1892*, Société d'éditions scientifiques, Paris, 592 p.

Renoux L., Dumas P., 1905. Culture du fonio dans la vallée du Sénégal et du Haut Niger. L'Agriculture pratique des pays chauds. *Bulletin du Jardin Colonial de Nogent*, novembre, 32, 357-367.

Richard-Molard J., 1944. Essai sur la vie paysanne au Fouta-Djalon. Le cadre physique - L'économie rurale - L'habitat. *Revue de Géographie Alpine*, 32 (2), 135-239.

Rivier M., Collignan A., Méot J.M., Sébastian P. 2016. Simulation model for the optimisation of coupling a biomass energy conversion unit to a cereal-based product dryer in developing countries. Submitted to Applied Thermal Engineering.

Rivier M., Cruz J.F. 2007. Étude de la précuisson du fonio au sein de petites entreprises de transformation à Bamako (Mali) et à Ouagadougou (Burkina Faso) In : Amélioration de la qualité et de la compétitivité de la filière fonio en Afrique de l'Ouest (J.F. Cruz, Éd.), [CD-Rom], Cirad, Montpellier, 38 p.

Rozis J.F., 1995. *Sécher des produits alimentaires : techniques, procédés, équipements*, Gret, Ministère de la Coopération, Paris, 344 p.

Samaké O., 2003. Integrated crop management strategies in Sahelian land use systems to improve agricultural producrivity and sustainability: a case study in Mali, thèse PhD, université de Wageningen, Pays-Bas, 132 p.

Sarr E., Prot J.C., 1985. Pénétration et développement des juvéniles d'une souche de *Meloidogyne javanica* et d'une race B de *M. incognita* dans les racines du fonio (*Digitaria exilis* Stapf). *Revue Nématol,* 8, 59-65.

Stapf O., 1915. Iburu and Fundi, two cereals of Upper Guinea (*Digitaria Iburua* ; *D. exilis*), Royal Botanic Gardens, Kew, Bulletin, 8, London, 381-386.

Stilmant D., Dupuis B., 2007. Réalisation d'expérimentations agronomiques sur le fonio. In: Amélioration de la qualité et de la compétitivité de la filière fonio en Afrique de l'Ouest (J.F. Cruz, Éd.), [CD-Rom], Cirad, Montpellier, 13 p.

Sudres A. 1947. La dégradation des sols au Fouta-Djalon. *Agronomie Tropicale*, 11 (5-6), 227-246.

USAID, 2008. *Chaîne de valeurs de la filière fonio au Sénégal*, International Resources Group, Washington DC, 90 p.

Vall É., Béavogui F., Sogodogo D., Daho B., Kanwé A., Diallo T.A., 2008a. Les facteurs de variation du rendement du fonio en milieu paysan (Guinée, Mali, Burkina) [Poster]. *In* : *La filière fonio en Afrique de l'Ouest* (J.F. Cruz, Éd.), [CD-Rom], Cirad, Montpellier.

Vall É., Dembélé K., Kanwe A., 2008b. Options pour le développement de la production de fonio. Projet Fonio. In : Amélioration de la qualité et de la compétitivité de la filière fonio en Afrique de l'Ouest (J.F. Cruz, Éd.), [CD-Rom], Cirad, Montpellier, 40 p.

Vall É., Daho B., Beavogui F., Sogodogo D., Kanwe A., Diallo T.A., Kollet Soumah M.A., Diallo S., 2007. Typologie des systèmes de production, base de données, identification des zones prioritaires d'intervention. Projet Fonio. In : Amélioration de la qualité et de la compétitivité de la filière fonio en Afrique de l'Ouest (J.F. Cruz, Éd.), [CD-Rom], Cirad, Montpellier, 38 p.

Vodouhè S.R., Achigan Dako E.G., 2006. *Digitaria exilis* (Kippist) Stapf. In : Prota 1- Cereals and pulses/Céréales et légumes secs (M. Brink et G. Belay, Éds), [CD-Rom], Prota, Wageningen, Pays-Bas.

Websites

Note: This list of useful websites is not exhaustive and must be regularly updated with search engines.

International/institutional websites

Thematic website on fonio:
http://fonio.cirad.fr/en/fonio

Aval Fonio project:
http://aval-fonio.cirad.fr/en

European INCO project on fonio:
http://inco-fonio-en.cirad.fr

Cirad website (France):
http://www.cirad.fr/en/home-page

IRAG (Institut de recherche agronomique de Guinée) website:
http://www.irag-guinee.org

IER (Institut d'économie rurale du Mali) website:
http://www.ier.gouv.ml

IRSAT (Institut de Recherche en Sciences Appliquées et Technologies) website:
http://www.cnrst.bf/index.php/irsat/

FAOStat database:
http://faostat3.fao.org/home/E

Information on post-harvest operations (INPhO):
http://www.fao.org/in-action/inpho/home/en/

Crops for the Future:
http://www.cropsforthefuture.org/

Bioversity International:
http://www.bioversityinternational.org/

Fonio and diabetes:
http://www.santediabete.org/en/

Private sector websites

Agrifood products from warm regions and recipes:
http://www.racines-sa.com/

Food processing and packaging unit in Mali:
http://www.ucodal.com/

Production of precooked fonio in Segou (Mali):
http://courantsdefemmes.free.fr/Assoces/Mali/SewaDjama/sewa-djama.html

Solidarity-based development in Guinea:
http://www.adesag.com/

Fonio from Gaia Bio Solidaire:
http://www.gaia-bio.fr/

Association of African food exporters (AAFEX):
http://www.aafex.com/index.php?lang=fr

Abbreviations and acronyms

ASSI: (Partnership between the following organisations): ADRAO (Association pour le développement de l'agriculture en Afrique de l'Ouest), SAED (Société nationale d'aménagement et d'exploitation des terres du delta du fleuve Sénégal), SISMAR (Société industrielle sahélienne de mécanique, de matériels agricoles et de représentations) and ISRA (Institut sénégalais de recherche agricole)

CEEMAT: Centre d'études et d'expérimentation du machinisme agricole tropical (Montpellier, France) (former CIRAD department specialised in tropical crop mechanization)

CFC: Common Fund for Commodities (intergovernmental financial institution established within the framework of the United Nations) (Amsterdam, Netherlands)

CIRAD: French Agricultural Research Centre for International Development (Montpellier, France)

CIRDES: International Centre for research and development in livestock farming in sub-humid areas, (Bobo-Dioulasso, Burkina Faso)

CRAW: Walloon Agricultural Research Centre (Libramont, Belgium)

ENDA: Environment development action in the third world (Dakar, Senegal)

FAO: Food and Agriculture Organization of the United Nations (Rome, Italy)

GERES: Group for the Environment, Renewable Energy and Solidarity (Marseille, France)

GMBF: Name of the fonio dehuller. GMBF stands for Guinea, Mali, Burkina, France

GRET: Professionals for Fair Development (Nogent-sur-Marne, France)

IER: Institut d'économie rurale du Mali (Bamako, Mali)

INRAB: Institut national de recherche agricole du Bénin (Cotonou, Benin)

IRAG: Institut de recherche agronomique de Guinée (Conakry, Guinea)

IRD: Institut de recherche pour le développement (Montpellier, France)

IRRI: International Rice Research Institute (Los Banos, Philippines)

NGO: Non-governmental organization

NRC: National Research Council (Washington D.C, United States)

SISMAR: Société industrielle sahélienne de mécanique, de matériels agricoles et de représentations (route de Rufisque, Dakar, Senegal)

SOCAFON: Société coopérative artisanale des forgerons de l'Office du Niger (Niono, Mali)

USAID: United States Agency for International Development (Washington D.C, United States)

VOTEX: Dutch machinery manufacturer (Middelburg, Netherlands)

Cover picture: Grains of fonio © Jean-François Cruz
Translation: James Brownlee, translator
Proof reading: Emma Morton Saliou
Layout: Hélène Bonnet
Printed by ISI print – July 2016

Fonio is considered a "minor" cereal compared to "major" cereals such as rice, wheat and corn.

However it is the staple food of many rural families in West Africa. It was recently 're-discovered' by urban consumers in major African cities and has appeared on European and North American markets, where it is mainly sold as a Fair Trade and exotic product.

Well suited to local conditions, this small grain can play an important role in the food security of southern countries, and in soil preservation by ensuring plant cover on ecologically vulnerable land.

This book–the first of its kind on the subject of fonio–provides a comprehensive study of this grain, from cultivation to processing, and even includes a few recipes. It is mainly intended for producers, technicians and development partners, but will also be of interest to anyone looking for information about fonio, such as teachers, students, agronomists, technologists, as well as curious consumers.

Jean-François Cruz is a research engineer at CIRAD (Agricultural Research Centre for International Development), in Montpellier. He specialises in cereal post-harvest technologies, and has coordinated several international projects on fonio. He has already published several works on grain preservation in hot regions.

Famoï Béavogui is Managing Director of IRAG (Guinea Agronomic Research Institute) in Conakry. He is an agronomics engineer, with a PhD in rural studies, and specialises in agricultural production systems and land dynamics.

Djibril Dramé is a food technologist. After working as a researcher at the food technology laboratory of the IER (Institute for Rural Economy) in Bamako, he is now an expert at the FAO Rural Infrastructure and Agro-Industries Division, in Rome.

Thierno Alimou Diallo is a plant breeder and long time manager of the "fonio program" of the IRAG (Guinea Agronomic Research Institute) Centre of Bareng in the Fouta Djalon.

cirad

CIRAD, UMR QUALISUD
TA B-95/16 - 73 rue Jean-François Breton
34398 Montpellier Cedex 5, France

IRAG, BP 1523
Conakry, Guinea

ISBN: 978-2-87614-720-1

9 782876 147201